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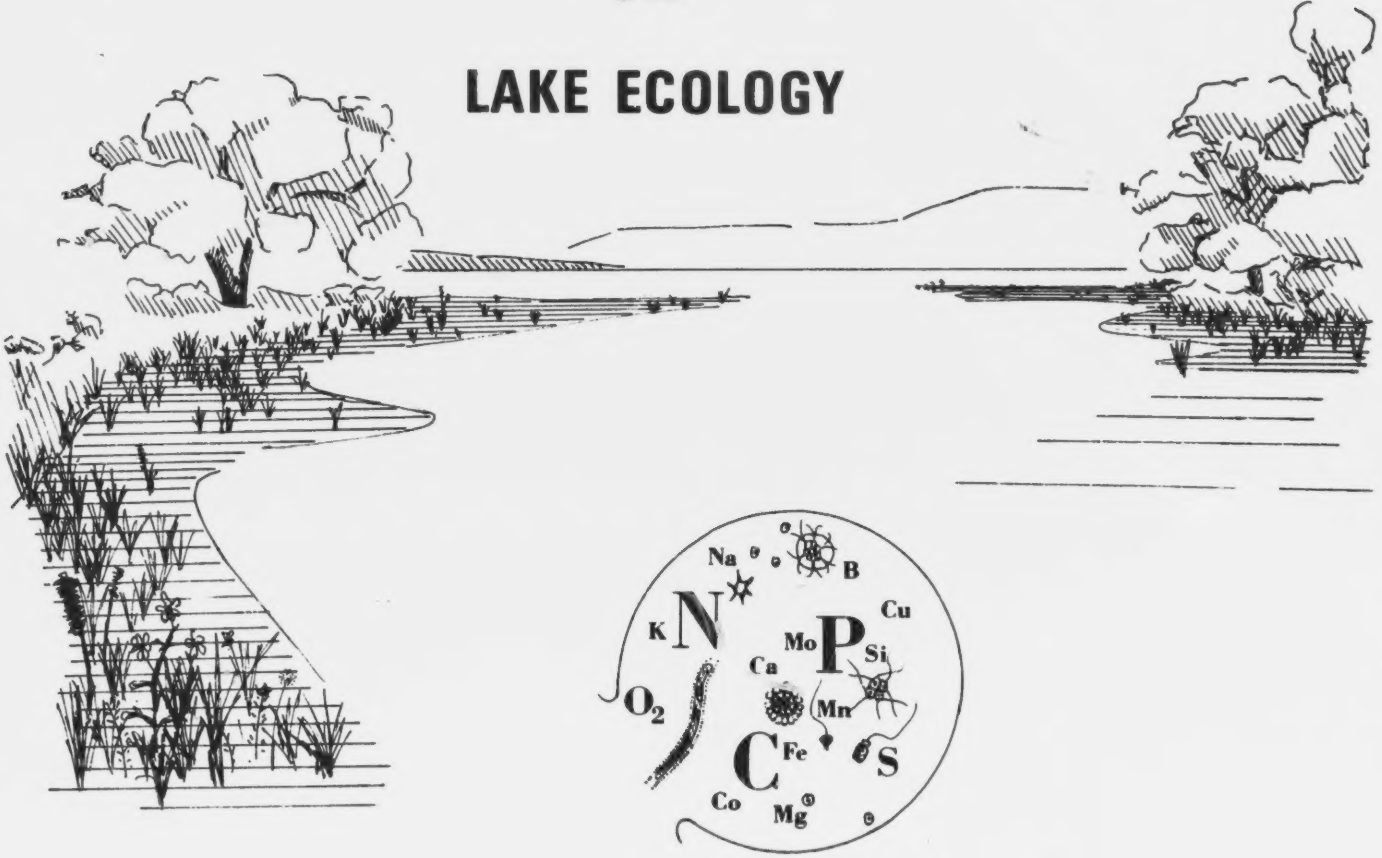

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Two Michigan lakes, eutrophic Lake Hemlock and oligotrophic Section Four Lake, were artificially aerated by compressed air from mid-June to September 7, 1970. Only the hypolimnion of the eutrophic lake was aerated which resulted in increased oxygen concentration from 0.1 mg/l to over 10.0 mg/l while thermal stratification was maintained. Zooplankton, zoobenthos, and fish distributed throughout the lake after aeration. Midges emerged from the deepest point. Aeration apparently reduced nutrient anaerobic regeneration but increased nutrient regeneration through aerobic decomposition of profundal sediments. Artificial destratification of the oligotrophic lake greatly increased the minimum temperature budget. Zoobenthos and surface phytoplankton standing crops were reduced but destratification had little apparent effect on the biota. Midges emerged from greater depths during aeration but depth distribution of organisms, other than crayfish, [redacted] not greatly altered. Following the summer artificial destratification, the winter oxygen concentration in Section Four Lake was 0.1 to 2.0 mg/l greater at all depths than the previous year; snow and ice cover were less. Hemlock Lake showed much higher oxygen at all levels during winter. Oxygen concentration was not only increased by aeration but the BOD was lowered. No appreciable winterkill occurred and many trout overwintered without any known ill effects. (Auen-Wisconsin)

*Aeration, *Methodology, *Lakes, Eutrophication, Hypolimnion, Winterkilling, Thermal stratification, Oligotrophy, Destratification

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THE EFFECTS OF ARTIFICIAL AERATION
ON LAKE ECOLOGY

By

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for the

ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

THE EFFECTS OF ARTIFICIAL AERATION ON LAKE ECOLOGY

By

Arlo Wade Fast

Two northern Michigan lakes were artificially aerated using compressed air. Hemlock Lake, a eutrophic lake, had only its hypolimnion aerated while thermal stratification was maintained. A special hypolimnion aeration device was used. Section Four, an oligotrophic lake, was completely destratified by releasing air from a perforated pipe at the deepest point in the lake. Both lakes were studied during 1969 under normal conditions, and during 1970 under test conditions.

Artificial hypolimnion aeration of Hemlock Lake caused oxygen concentrations to increase from 0.0 mg/l to over 10.0 mg/l while thermal stratification was maintained. Zooplankton, zoobenthos and fish distributed throughout the lake after aeration, while limited to shallow depths before. Midges emerged from the deepest point following aeration. Aeration apparently reduced anaerobic nutrient regeneration, but increased nutrient regeneration through aerobic decomposition of the profundal sediments. These sediments were highly organic and incompletely decomposed due to the previous anaerobic conditions.

Artificial destratification of Section Four Lake greatly increased the minimum temperatures and heat budget. Although zoobenthos and surface phytoplankton standing crops were reduced, destratification had little apparent effect on the biota. Midges emerged from greater depths during aeration but depth distributions of most organisms, other than the crayfish, were not greatly altered. Crayfish distributed evenly throughout the lake during aeration. Changes in their distribution suggests that the thermal gradient and aggressive behavior of the male are the most important factors determining their normal depth distributions.

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INTRODUCTION

Essentially all temperate lakes follow thermal stratification cycles. Yearly cycles are the most important and have the greatest influence on lake processes. Chemical and biological stratification are related to thermal stratification.

Typical temperate lakes are isothermal in the spring. As the seasons progress, the upper lake water is heated faster than the lower. Wind generated water currents distribute this heat to the lower depths. Wind mixing efficiency decreases greatly with increasing depth and the lake is divided into three thermal zones by early summer: (i) Epilimnion. The warm water zone. It is circulated by the wind and oxygen concentrations are generally near saturation. Temperature and chemical properties are nearly homogeneous throughout. Daily and seasonal temperature variation is much greater here than in the other zones. Most of the biota is restricted to this zone in eutrophic lakes. (ii) Metalimnion. A zone of rapid change in temperature, density and chemical properties. Characterized by a $1.0^{o}C$ or greater change per meter change in depth.
(iii) Hypolimnion. The cold water zone of the lake. This zone is sealed off from the surface. It characteristically

stagnates by early summer in organically rich, eutrophic lakes. Stagnation results in an oxygen deficit, buildup of hydrogen sulfide, increased iron, phosphate and manganese concentrations, anaerobic conditions and overall deterioration of water quality. Aerobic biota are often excluded from the hypolimnion of eutrophic lakes. The rate of hypolimnetic oxygen depletion is a measure of the lake's organic richness. Organically poor, oligotrophic lakes characteristically do not develop oxygen depletions. Oligotrophic lakes differ markedly in their chemical and biological properties although their temperature regimes are similar to eutrophic lakes. Chemical concentrations are often uniform throughout oligotrophic lakes and restrictions to biotic distributions are minimal. Anaerobic biota are either conspicuously absent, or restricted to subsurface mud. Hypolimnetic biotic concentrations can be greater than epilimnetic concentrations.

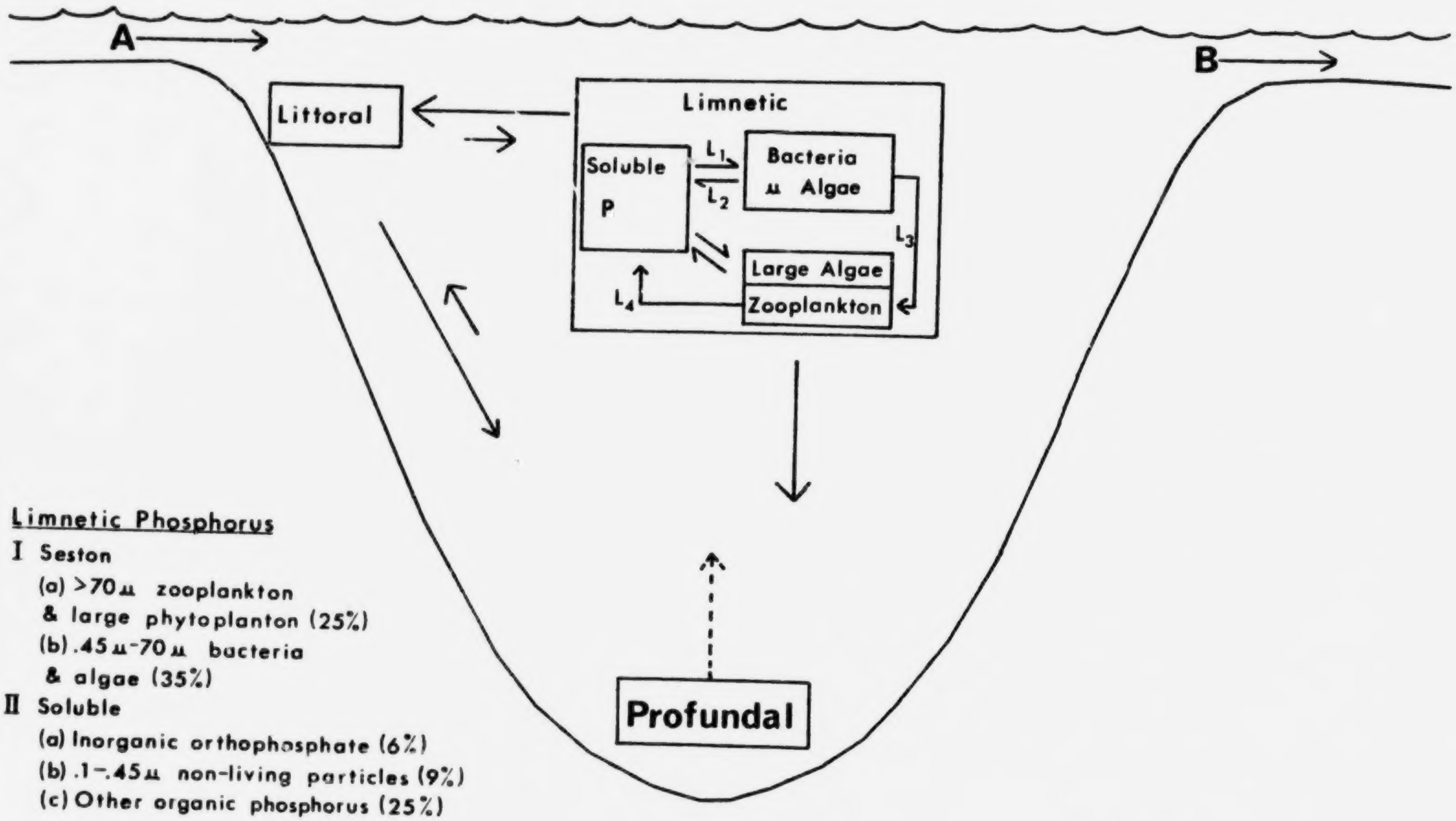
As the seasons progress, the epilimnion cools and approaches the hypolimnion temperature during late summer and fall. The lake becomes isothermal again during the fall. Most temperate lakes develop ice cover and inverse thermal stratification during the winter. The coldest water, at 0.0°C, is just under the ice, whereas warmer water at about 4°C is near the bottom of the lake. Chemical and biological values often stratify in response to this winter thermal stratification. Oxygen may be completely depleted from eutrophic lakes during the winter with a resultant loss of aerobic biota. Oligothrophic lakes generally have high oxygen concentrations all winter at all depths.

Lake stratification often conflicts with man's exploitation of the water body. Thermal stratification of eutrophic lakes often results in deterioration of drinking water quality, anaerobic and corrosive conditions, increased evaporation rates, reduced heat budgets and other undesirable properties within the lake. Stratification of oligotrophic lakes is generally not undesirable.

In general, lakes are thought to undergo a succession from oligotrophy through mesotrophy and eutrophy to dystrophy (Lindeman, 1942). This natural process is called eutrophication. Accelerated and undesirable eutrophication due to man's activities is termed organic pollution. Although lakes may enter this scheme at any point based on their origin, morphometry, and other factors, they generally progress towards dystrophy and extinction. Productivity per unit area increases at least through the eutrophic stage and may decline at dystrophy due to volume reduction and unfavorable conditions, such as low pH. Increased productivity is associated with higher nutrient levels and oxygen depletion of deep water during periods of stagnation. Indeed, this loss of oxygen is seen as a pivot point between oligotrophy and eutrophy. Aging is greatly accelerated once eutrophy is attained. Oxygen depletion is often credited with greatly accelerating eutrophication since anaerobiosis results in accelerated generation of nutrients from profundal sediments. These sediments are rich in essential nutrients, especially phosphorus. Although many factors may limit production in a given system at a given time, phosphorus is generally the one most limiting factor in a cosmopolitan spatial and temperal sense; especially of primary production. Considerable effort has been expended trying to define its behavior in lakes, but its movements and forms are still very poorly understood. Although our understanding is imperfect, certain characteristics are apparent. Much of the following phosphorus discussion is based on a conversation with Dr. F. H. Rigler of the University of Toronto. The fact that lakes act as nutrient traps is of special importance when considering the phosphorus cycle. Only 20 to 70% of the phosphorus entering a lake will leave the lake (Figure 1; B = (0.2 to 0.7) x A). The remainder, 30 to 80%, remains in the lake and most of this ultimately resides permanently in the sediments.

The behavior of phosphorus before its eventual sedimentary incorporation determines the level of eutrophication. In general, the greater the amount of phosphorus in circulation, the more eutrophic the lake will be. Our conceptualization of phosphorus cycling in a lake is facilitated by envisioning compartments that roughly correspond to the major lake zones. Phosphorus behavior within each compartment is somewhat independent of its behavior within the other compartments, but the compartments are very much interrelated. The three general compartments are limnetic, littoral and profundal. Phosphorus is exchanged between these compartments, as well as within components of each compartment. Relationships within the limnetic and littoral compartments are probably the most complex, and those within the former are best understood. The components, or forms limnetic phosphorus assumes can be categorized as sestonic and soluble (Figure 1). Each category is again divisible into subcategories. These categories appear discrete, but in fact there is much overlap. In a static sense, about 70% of the total phosphorus is found within the sestonic forms. In a dynamic sense this picture may be reversed since the movements between components is very rapid. For example, although soluble inorganic phosphorus probably represents less than 6% of the total limnetic phosphorus at any given time, its turnover rate is from 1 to 7 minutes. The small algae and bacteria are most important in this movement. The main pathway within the limnetic compartment is from soluble phosphorus to the bacteria and in algae (L_1). Phosphorus then moves back to the soluble form (L_2) and into the zooplankton (L_3) in about equal proportions ($L_2 \simeq L_3$). Phosphorus is also directly taken up by larger limnetic algae and zooplankton, but at a lesser rate. Zooplankton excrete and secrete phosphorus, with secretion exceeding excretion (Johannes and Satomi, 1967; Rigler, 1964). Most of the zooplankton-voided

Figure 1. Hypothetical phosphorus cycle within a lake showing the three main compartments. The components of the littoral compartment are also shown.


A
B
Littoral
Limnetic
Soluble P
Bacteria µ Algae
Large Algae
Zooplankton
L_1
L_2
L_3
L_4
Profundal

Limnetic Phosphorus

- I Seston
  - (a) >70µ zooplankton & large phytoplanton (25%)
  - (b) .45µ-70µ bacteria & algae (35%)
- II Soluble
  - (a) Inorganic orthophosphate (6%)
  - (b) .1-.45µ non-living particles (9%)
  - (c) Other organic phosphorus (25%)

phosphorus is orthophosphate. The dynamics of these exchanges and those between lake compartments is such that the concentration of the soluble component does not fluctuate widely. The rates of movement within compartments and between compartments is probably the key factor controlling eutrophication. The vast majority of studies have measured only static phosphorus concentrations within certain compartments. These measurements have contributed something to our understanding of the role phosphorus plays, but all too often they have led to confusion and conflicting conclusions. Rates of movement in a total lake system have not been thoroughly analyzed.

We know that ultimately most of the phosphorus ends up in the profundal compartment, and there is a net movement out of the limnetic compartment. Hutchinson and Bowen (1947) indicate the net movement is from the littoral to the limnetic to the profundal. Rigler (1956) and Coffin et al. (1949) later found a net movement during the summer from the limnetic to the littoral with less than 5% from the limnetic to the profundal. Presumably there was a net movement from the littoral to the profundal especially during the fall and winter breakup of littoral vegetation. McCarter et al. (1952) have shown that very little phosphorus moves from the profundal to the other compartments during thermal stratification, but no studies to date have evaluated movements between compartments on a yearly basis. They are all incomplete and taken singularly often lead to misinterpretations.

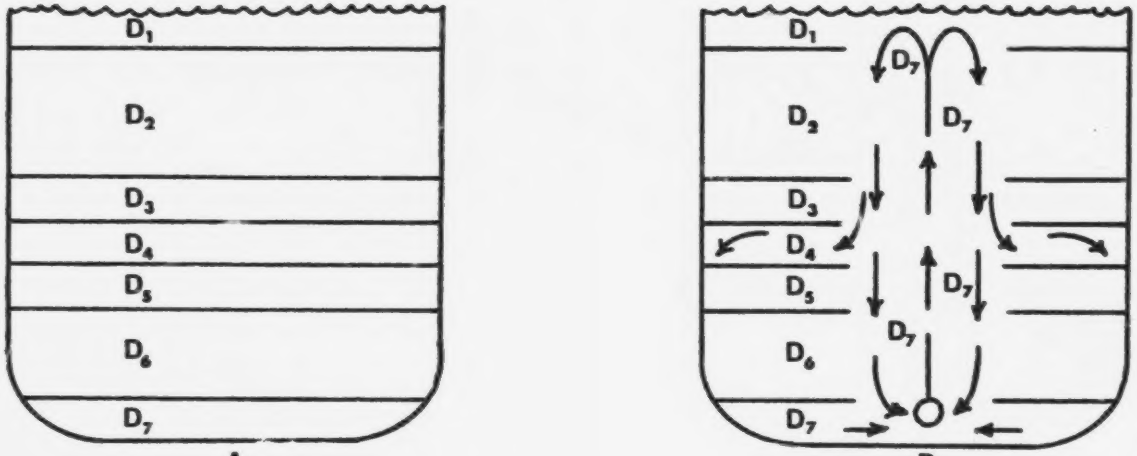
The movement of phosphorus between the profundal compartment and the trophogenic zone is especially important in understanding eutrophication in general, and the specific applicability of artificial aeration as a corrective measure for eutrophication. As discussed, the onset of profundal oxygen depletion is considered a most important event in the eutrophication process. Anaerobiosis may result in a significant increase in nutrient movement from the profundal compartment back into the limnetic and littoral. This movement occurs mostly during spring and fall overturns. Before anaerobiosis, phosphorus was tightly held by the aerated sediments and little was returned during overturns. After anaerobiosis, a large, but undetermined quantity is returned to the trophogenic zone. What fraction this represents of the total input to the profundal compartment is unknown. If this fraction is relatively small, then the onset of anaerobiosis may represent only a signpost on the road to dystrophy and our efforts to retard eutrophication by aeration will be ineffective. In this case, the total input of phosphorus to the lake is seen as the dominant factor. Studies on artificial fertilization infer this may be the case. Artificially fertilized lakes typically return to their former level of production soon after nutrient input ceases, even though prodigious quantities of nutrients were added and a high degree of anaerobiosis was attained.

On the other hand, if anaerobiosis results in the return of a significant fraction of nutrients to the trophogenic zone, then artificial aeration may be a useful method of reversing eutrophication. This would be achieved by keeping the profundal sediments well oxidized and thus preventing the release of nutrients once they were incorporated in these sediments. This also assumes that the nutrient input into the lake is not accelerated. If it is, this may more than compensate for reduced regeneration from the profundal compartment and many of the characteristics of eutrophication would not diminish. In any case, the anaerobiosis would be diminished or eliminated by artificial aeration. This is not always the most important characteristic, however. This in essence forms the basis of my artificial hypolimnion aeration of Hemlock Lake. Rather than attempt to measure changes in phosphorus transfer rates from the profundal zone associated with artificial aeration, I chose to measure certain biotic parameters and thereby infer changes in the phosphorus transfer rates. This approach has two important advantages: (1) it is probably impossible to accurately measure phosphorus transfer rates with our present technology, while biota parameters are estimable in many cases, and (2) the effects of aeration on the biota are ultimately the most important factors. Although we may not materially affect phosphorus regeneration from the profundal sediments, some other event related to the aeration may result in reduced biotic productivity. Thus the net effect might be desirable, although the effect on regeneration might be inconsequential. This is in fact how many important scientific advances occur. We first find out what will work, and later possibly how it does work. The major disadvantage of monitoring only the biota is that results not conforming to the theory are very difficult to explain. To be sure, direct measurement of phosphorus movements is desirable, but impossible from a practical standpoint.

Until recently, little was done to economically reduce stratification. Artificial destratification was attempted with mechanical pumps (Hooper et al., 1952; Irwin et al., 1969), but this method is generally slow and relatively inefficient. Several artificial destratification techniques using compressed air have been developed. Fast (1968) reviewed several of these techniques in greater detail. Their common principle is that compressed air is released near the bottom of the thermally stratified lake. The rising air generates vertical water currents that diverge horizontally upon reaching the lake's surface (Figure 2). This upwelled water is much colder and denser than the surface water. Upon converging with the warm surface water and sinking, the cold water mixes with the epilimnion and metalimnion water along its periphery to form water of intermediate temperature and density.

This mixed water now spreads out horizontally at levels of equal density. The depth of outflow depends on the degree of mixing and initially may be confined mostly to the metalimnion. As the mixing process progresses, the shape of

Figure 2. Hypothetical destratification patterns caused by diffuse aeration system. Figure A illustrates a stratified lake, and Figure B a lake being destratified.


D₁
D₂
D₃
D₄
D₅
D₆
D₇
D₁
D₇
D₂
D₇
D₃
D₄
D₅
D₇
D₇
D₆
D₇

A. B.

$D_1 < D_2 < D_3 < D_4 < D_5 < D_6 < D_7$

D = density

the iso-density strata changes. Concomitant with this change is a change in the rate of mixing. The rate of destratification is greatest when air injection begins and approaches zero apparently as an exponential function as the lake approaches isothermy (Koberg and Ford, 1965). The lake will approach either an isothermal or a steady-state condition as the mixing continues. The time it takes to reach this condition depends on the time of year, size of lake, and method of injection. The best method of injection and equipment specifications for a given lake situation is not well defined.

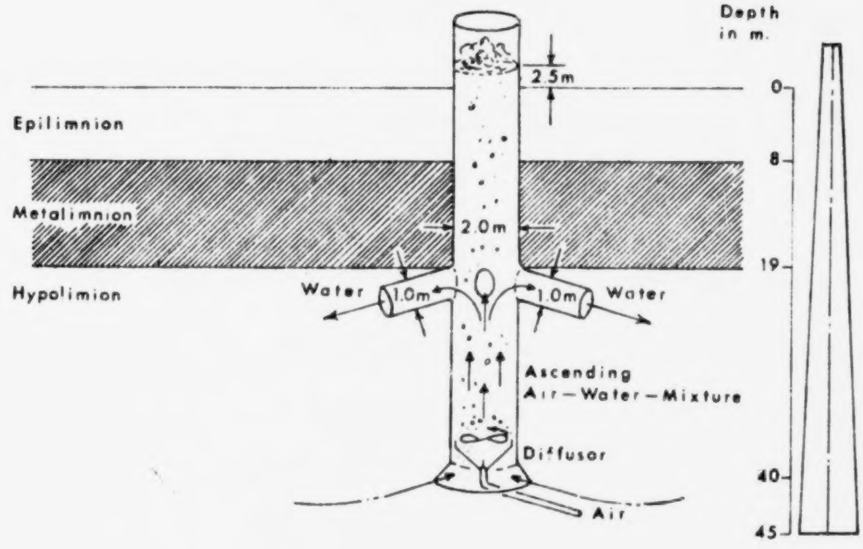
Artificial destratification of a lake by compressed air is commonly called "lake aeration." The reasons for this are two-fold: (1) Eutrophic lakes experience an oxygen deficit below the metalimnion during the summer. By artificially circulating the lake, the oxygen deficit is reduced or eliminated, and (2) compressed air is used to circulate the water. While the compressed air adds oxygen directly to the upwelled water, oxygen is also gained from contact of the water with the atmosphere and by photosynthesis of aquatic plants. The term "aeration" applied to oligotrophic lakes is somewhat of a misnomer since these lakes typically have adequate oxygen levels. Destratification and aeration are generally used synonymously.

The purpose of artificial destratification is to reduce the density barrier to complete circulation. After artificially induced circulation of a reservoir, the water temperature is about equal from top to bottom and many of the chemical properties are likewise homogeneous. The whole water mass and bottom area is theoretically habitable by the aerobic biota which otherwise could only inhabit the epilimnion and metalimnion of a eutrophic lake.

Artificial destratification also increases the lake's heat budget. After destratification, the entire lake is about as warm as the epilimnion before aeration began. This warming occurs with continuous air injection (Fast, 1968), as well as intermittent air injection (Fast and St. Amant, manuscript in preparation). Although an increased heat budget generally benefits eutrophic lakes, it may have serious repercussions in oligotrophic lakes by eliminating those cold water organisms inhabiting the hypolimnion.

A new method of aerating the hypolimnion of eutrophic lakes was more recently developed (Bernhardt, 1967). Using Bernhardt's aerator (Figure 3) the hypolimnion is aerated but not greatly heated. Hypolimnion aeration is only applicable to eutrophic lakes, since oligotrophic lakes already have high oxygen concentrations. Bernhardt's aerator consists of a large diameter pipe extending from the lake bottom to above the lake surface. Inlet ports are located near the bottom of the pipe and outlet ports are located below the metalimnion. The top of the pipe is open to the atmosphere. Air is released and passes through a diffusor near the bottom of the pipe. As air rises in the pipe, water is drawn in

Figure 3. Hypolimnion aerator of Bernhardt (1967). From Fast (1968).


Depth
in m.
2.5m
0
Epilimnion
8
Metalimnion
2.0m
19
Hypolimion
Water
1.0m
1.0m
Water
Ascending
Air–Water–Mixture
Diffusor
40
Air
45

through the bottom ports and rises. Oxygen diffuses into the water as it rises. Water and air are carried to the top of the pipe where the air escapes to the atmosphere. The water, however, cannot escape at the surface and sinks to the outlet port level where it flows back into the hypolimnion. Once a hydraulic head is established in the pipe, water may flow directly from the inlet to outlet ports without rising to the top of the pipe. Consequently, hypolimnion water is aerated, but not significantly heated or mixed with epilimnion or metalimnion water. Thermal stratification is not affected by this technique if the outlets are below the metalimnion.

Bernhardt used his hypolimnion aerator in Wahnbach reservoir near Siegberg, Federal Republic of Germany. This domestic water supply reservoir is about $37\text{x}16^6$ cubic meters volume with 43.4 meters maximum depth. His main objective was to supply cold, well-oxygenated water for domestic and industrial uses. Previously, he used a diffused air injection system to aerate the water, but this technique increased the water temperatures to undesirable levels.

Bernhardt estimates $0.167\text{x}10^6$ cubic meters per day are aerated by the hypolimnion aerator using about 117 cfm of compressed air. Contact time within the aerator is about 54 seconds and increases the oxygen concentrations from about 5 mg/l to about 10-11 mg/l at steady state.

Oxygen transfer occurs primarily within the bottom 7.5 to 20.0 meters of pipe and decreases rapidly thereafter.

This is primarily a function of: hydrostatic pressure, oxygen saturation of the water, oxygen content of the air bubbles, and bubble size. As water and air rise higher in the pipe, conditions for oxygen transfer become progressively less favorable. It may be possible to increase the oxygen concentration of the hypolimnion to greater levels than found in the epilimnion or metalimnion. This is possible because of the greater hydrostatic pressures and lower temperatures of the hypolimnion water.

My present investigation actually consisted of two separate, but related aeration studies. One oligotrophic lake, Section Four Lake, was thermally destratified. This study was conducted principally to determine the effects of an increased heat budget on the coldwater biota and the other characteristics of the lake. This is one of the first studies to evaluate the influence of continuous summertime destratification on a oligotrophic lake. Most destratification studies were conducted on eutrophic lakes where the benefits from and needs for artificial destratification are greatest.

Hemlock, a eutrophic lake, was aerated with a new hypolimnion aerator of my own design. This study was conducted principally to determine the value of this aeration system for eutrophication control and to evaluate its effect on the vertical distribution of rainbow trout (Salmo gairdneri). While Bernhardt (1967) was mainly interested in improving water quality by artificial hypolimnion aeration, I am more interested in the specific effects of this aeration system on the biota.

The experimental design is essentially the same for both lakes. The lakes were studied under natural conditions during 1969 and artificially aerated during 1970. Special emphasis was placed on the oxygen, temperature, zoobenthos and rainbow trout depth distributions.

METHODS

The transect method was used to collect most samples. A rope extended from a post on shore to a steel barrel anchored near the center of the lake (Figures 4 and 5). A pontoon raft was hand-pulled along the rope and samples collected as desired. Unless otherwise indicated, samples were collected at the barrel. The summer sample periods extended from June 15, 1969 through September 5, 1969 and from June 7, 1970 through September 7, 1970. In addition, one set each of oxygen, temperature, pH, alkalinity and conductivity measurements were made during December 1969, January 1970, December 1970 and January 1971.

Physical-Chemical

Water samples for chemical determination were collected each two meter depth interval from each lake with a PVC plastic water sampler. Samples for pH, alkalinity and conductivity were placed in plastic bottles at the lake and taken to the laboratory for analysis. Total alkalinity and pH were measured with a glass electrode pH meter. A 4.4 pH endpoint was used for total alkalinity. Specific conductance was measured on a Type RC, Industrial Instruments conductivity

Figure 4. X-sectional view along principle sample transect. Raft, emergent insect traps, gill nets and transect float are shown.

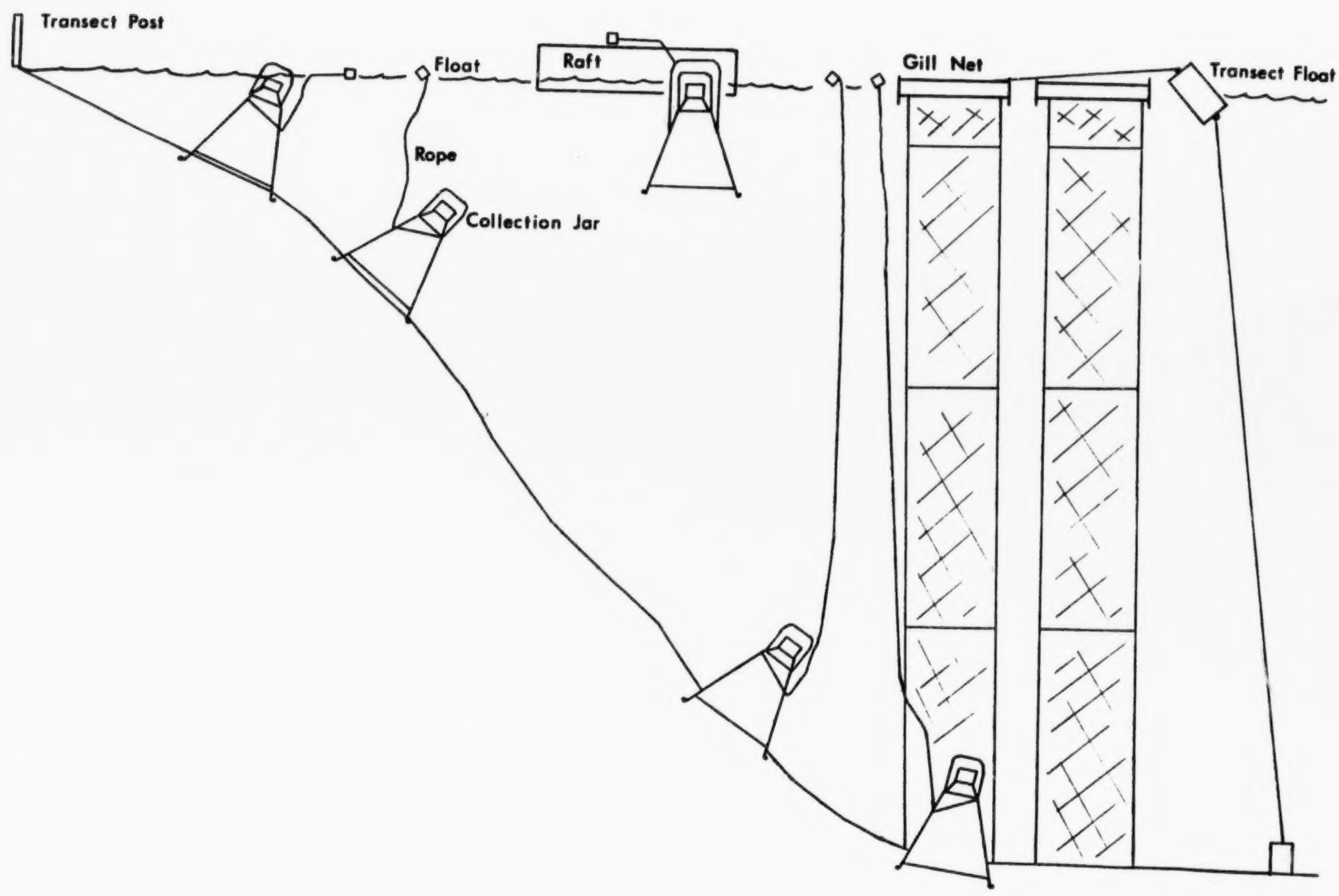

Transect Post
Float
Raft
Gill Net
Transect Float
Rope
Collection Jar

Figure 5. View of Section Four Lake taken from basin rim. Emergent insect traps are stacked on the raft. The periphyton float is to the left of the transect barrel, and the gill net rollers are to the right of the barrel. (Photo by Dr. O. E. Kurt.)

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bridge during 1969, and on a different Type RC bridge during 1970. A correction value was determined for each instrument.

Temperature-depth measurements were made with a resistance thermometer at weekly intervals or less. Thermal stability was calculated from temperature data as described by Fast (1968) using Schmidt's (1915) and McEwen's (1941) formulations.

Most oxygen determinations were made from water samples collected with the PVC water sampler. A few sets of determinations during June 1970 were taken with a Precision galvanic cell D.O. analyser. Oxygen values were determined by the Alsterberg modification of the Winkler method, except that Phenylarsene oxide (PAO) was substituted for thiosulfate and thyodene was substituted for starch solution. Samples were taken weekly during the summer 1969, most of the summer 1970, and each winter from one location, but were taken more often from both lakes during June 1970. In addition to the standard sampling location in Hemlock Lake, depth samples were taken at several locations along a transect from the aeration tower to a point near the compressor. Most of the Hemlock Summer 1970 and January 1971 oxygen and temperature measurements were made along this transect.

Transparency was generally measured daily with a standard black and white 20-cm secchi disc. Only one set of light transmittance measurements were made in each lake with a subsurface photometer.

Carbon dioxide concentrations were estimated using a monograph from pH and total alkalinity values (Moore, 1939).

Total dissolved organic matter, total particulate organic matter, Ca, K, Na, and Mg were analyzed by R. G. Wetzel. He used slight modifications of Stickland and Parsons' (1965) methods for DOM and POM; and simple atomic absorption for the cations (Jarrell-Ash Model 82-700).

Relative irradiance measurements were made with a submarine photometer. Both deck and submerged cells were used without filters.

Chlorophyll analyses were made only once. Water was filtered through Whatman GFIC glass filters. A small quantity of magnesium carbonate was placed on the filter to prevent acidification and the filters were stored at about -23°C. Samples were macerated with a tissue grinder and chlorophyll extracted for 24 hours in 90% acetone. Optical densities were measured over a 1.0 cm pathlength. Chlorophyll values were computed using formula of Parsons and Strickland (1963) and Lorenzen (1967).

Area-capacity values are based on topographic maps constructed by the Institute for Fisheries Research, Michigan Department of Natural Resources. They constructed these maps from surveys made of each lake during January 1957. I constructed area-capacity tables (Tables A-9 and A-10) from these maps as described by Welch (1948).

Phosphorus measurements were made in both lakes during 1969. Samples were collected in glass bottles and a portion of each was filtered through HA millipore filters. The samples were then acid-digested and analyzed using the stannous chloride method for orthophosphate (American Public Health Association, 1965). Total phosphorus and total soluble phosphorus were calculated from these measurements.

Sediment total carbon content was measured using a new method developed by Dr. Frank D'Itri of Michigan State University. Briefly, a finely ground sample of dry sediment (dried at 105°C) is oxidized by heating with potassium dicromate and concentrated sulfuric acid. Carbon dioxide is produced in proportion to the amount of carbon present. The carbon dioxide is absorbed by sodium hydroxide and determined gravimetrically. Sediment carbonate content was measured using an acid neutralization method (Allison and Moodie, 1965). Organic carbon is estimated by the difference between total carbon and carbonate carbon.

Phytoplankton

Brian Moss identified and counted the phytoplankton. Three 500-ml samples were collected twice a week from each lake during 1969. These samples were collected from 0, 5 and 15 meters depths. One ml of Lugol's solution was added and the samples were shipped to East Lansing for examination. During 1970, 11 samples were collected each time from Hemlock and 9 from Section Four. One thousand ml were collected for each sample, and collections were taken once or twice a week. These samples were placed in plastic graduated cylinders, four ml of Logol's was added and they were allowed to settle for two days. After two days, the supernate was drawn off through a small glass tube inserted in the side of the cylinder. About 30 ml of concentrate remained after decanting. This was drawn off through a larger glass tube inserted at the bottom of the cylinder. The cylinder was rinsed with distilled water and added to the concentrate. About 60 ml of concentrate was thus obtained. This was shipped to East Lansing for examination.

A subsample of each sample was filtered through a HA millipore filter. After filtering, a drop of oil was added and the sample examined at 150x to 600x magnifications. From 10 to 50 fields were examined, depending on the algal concentrations, to give an estimated ± 5% error.

Primary Production

Primary production estimates were made using the carbon-14 technique in a constant light intensity chamber (Figure 6 (a). Water samples were collected with a PVC water sampler and transferred to 125 ml Pyrex bottles. One light bottle and one dark bottle were collected from 0.3 m. These samples were immediately placed in a light tight box and taken to the incubation chamber. About 25 minutes passed between

Figure 6. (a) Phytoplankton incubation chamber. Four submerged sample bottles on the rotating wheel. (Photo by author.)

(b) Periphyton ring. Five plastic periphyton slides are visible clamped to the ring. (Photo by author.)

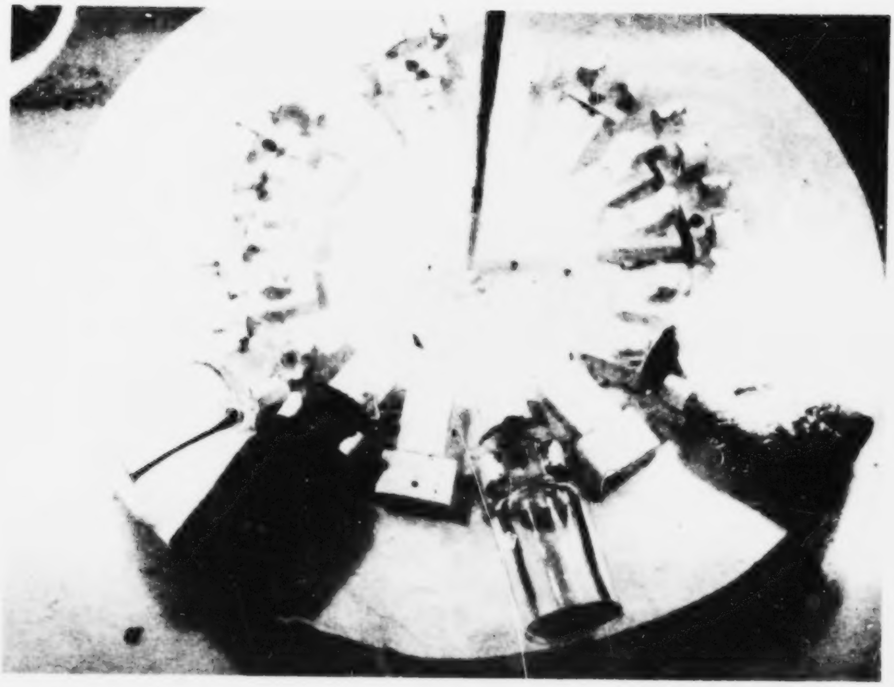

Fig. 6a

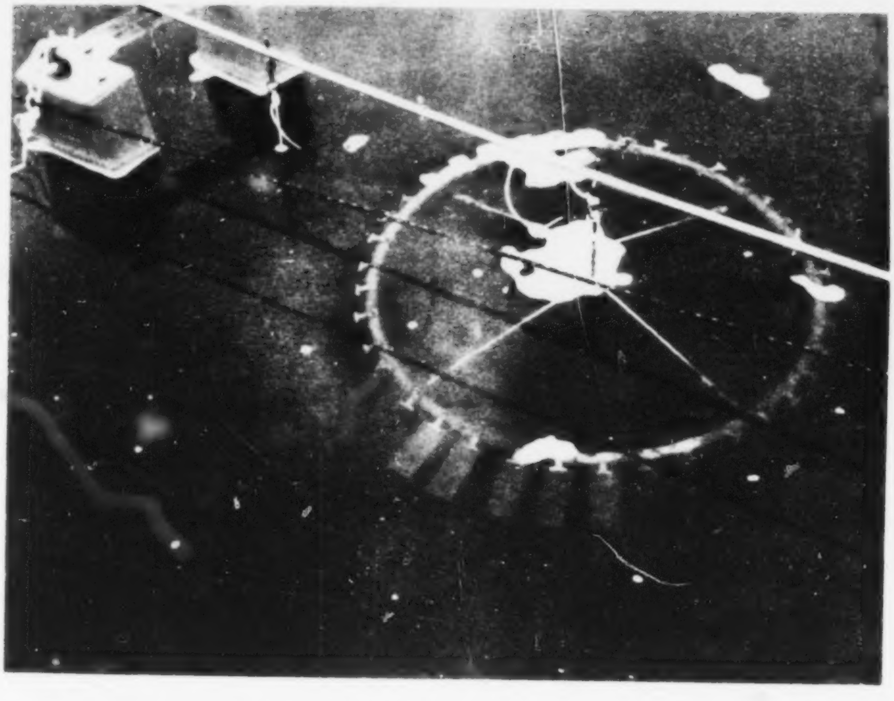

Fig. 6b

collection and incubation. Each Hemlock Lake sample was inoculated with 1.0 uc ^{14}C in 1.0 ml distilled water both years. Each Section Four sample was inoculated with 1.0 uc in 1.0 ml distilled water during 1969, but 2.0 uc in 20 ml distilled water during 1970. The samples were incubated in the light chamber for four hours. They were placed on their side on a revolving horizontal wheel. The wheel was 45 cm in diameter and turned at 5 revolutions/min. The water was usually kept within 5°C at the lakes' surface temperatures. The bottles revolved 33 cm from 6 Sylvania Gro-Lux, 20-watt fluorescent bulbs and 20 cm (minimum distance) from two G.E., 150-watt spotlight bulbs. After incubation, 50 ml of Hemlock sample was filtered through a 25 cm diameter HA millipore filter (0.45 u). Fifty ml of each Section Four sample was filtered during 1969, but 100 ml was filtered during 1970. Each filter was rinsed with three percent formalin after the sample water had passed through. After drying in the dark, the filters were exposed for 15 minutes to HCl fumes (Wetzel, 1965). Sample activity was measured using a Tracerlab Omniguard Low Background, internal gas flow Counting System; the efficiency of which was determined from samples of known activity. Efficiency averaged about 12%. Total inorganic carbon available for photosynthesis and the rate of carbon fixation was estimated using Saunders et al. (1962) method.

Periphyton

Periphyton standing crop was measured as ash-free dry weight. The periphyton grew and collected on 6mm x 50mm x 127mm plexiglass slides that were suspended horizontally in the lake at six depths. The slides were fastened with metal clips to a plastic ring (Figure 6 (b)). The ring was suspended by rope from a horizontal bar held above the lakes' surface by floats. One series consisted of four slides at each depth. These were usually incubated 17 days before collection. The second series consisted of three slides at each depth. These samples were incubated 34, 51 or 68 days and represented total, undisturbed accumulations during the sample period. Periphyton samples were scraped from the slides and stored in 90% ETOH at -15°C until dried. They were dried at 105°C four days and held in a dessicator until incinerated. They were incinerated at 550°C for 10 minutes. They were cooled in the dessicator before weighing. Weights to the nearest 0.1 mg were measured. All periphyton weights collected are presented in the Appendix (Tables A-1 through A-4).

Zooplankton

Two series of zooplankton samples were collected during 1970. Three samples from each depth were collected by filtering 22 liters of water through a Wisconsin plankton net. The net was suspended on the pontoon raft and water was pumped via a garden hose into the net. About 8 liters of water per minute were pumped. The concentrated zooplankton were preserved in 3% Rose Bengal solution made from 90% ETOH. The stained specimens were later filtered through a HA millipore filter with a printed grid. The filter was then placed over a drop of glycerin in a plastic millipore petri dish. This gave a permanent mount and the grid facilitated counting.

Zoobenthos

Zoobenthos samples were collected along one transect in each lake with a screened Ekman 15-cm square dredge (Welch, 1948). The screen was No. 30 brass sieve. Five samples were collected from each depth interval each sample period. Five collections were made in each lake each year, and the depth intervals in meters were: 0.0-3.7, 3.7-7.3, 7.3-11.0, 11.0-14.6, and 14.6-maximum depth. Maximum depth was 18.6 meters in Hemlock and 19.1 in Section Four. Collections were made at three-week intervals beginning in mid-June each year. A total of 125 samples were collected from each lake each year. Samples were sifted through a No. 30 brass sieve (0.59 mm opening) at the lake and later preserved with 20% formalin. Reisch (1959) found that about 93% by biomass of his marine zoobenthos were retained by a No. 20 sieve. The No. 30 sieve used in this study probably retained comparable biomass, but Jonasson (1955) has shown that zoobenthos population estimates can be biased by sieve size. These samples were later stained with a 3% Rhodamin B solution in 90% ETOH and sorted into 90% ETOH using Anderson's (1959) sugar flotation technique. An illuminated magnifier (2x) lamp was used in the sorting. Fast (1970) found the efficiency of sugar flotation is high for such groups as midge larvae and pupae, but much lower for oligochaetes. I feel these efficiencies were somewhat greater in my present study because the present samples were stained and a better magnifier was used to sort. Sixteen zoobenthos categories were identified, and organisms were sorted into these categories. These include: oligochaetes (microdriles), oligochaetes (megadriles), Chironomid larvae, chironomid pupae, amphipods, dragonflies (Anisoptera), damselflies (Zygoptera), mayflies (Ephemeroptera), Chaoborus spp. larvae, Chaoborus spp. pupae, clams, Heleidae (=Ceratopogonidae) larvae, Trichoptera larvae, Tabanid larvae, Megaloptera and leeches. No attempt was made to determine relative species compositions of each category, but representative specimens of certain categories were sent to taxonomists for the respective group. The number of organisms in each category were counted for each sample, and their wet weight measured to the nearest 0.001 mg. Before weighing, excess moisture was removed using King and Ball's (1964) technique, but were centrifuged for 4 minutes instead of 30 seconds. All numeric and weight data are presented as wet weights in the Appendix (Tables A-5 through A-8).

Crayfish

Crayfish (Orconectes virilis) were collected with modified wire minnow traps (Momot and Gowing, 1970) suspended from the transect line at ten depths. After collection they were either removed from the lake, or released near the center of the lake. Four collections were made from each lake between August 12 and August 30, 1969, but 22 collections were made from each lake between June 7, 1970 and September 4, 1970. Times between collections varied from one day to one week. Crayfish were sexed upon collection.

Emergent Insects

Emergent insects were captured using a new half-square meter submerged trap (Figure 7a). The trap has a steel frame on which clear polyethylene plastic is attached. On hard substrate, it is held off the bottom by legs, thus permitting water to circulate between the trap and the lake. A glass jar is attached to the top of the trap and collects the insects as they rise to the surface. A removable funnel and perch apparatus is situated in the jar mouth (Figure 7b). The funnel is made from two styrofoam drinking cups. The bottom cup has a small hole in its top to permit entry of the insects and fine mesh netting on one side. The other styrofoam cup has most of its sides cut away and is glued to the first cup to form a perch for emerged insects. Water is added

Figure 7. (a) New emergent insect trap. (Photo by Dr. O. E. Kurt.)

(b) Styrofoam trap used in collection jar on the emergent insect trap. (Photo by Dr. O E. Kurt.)

(c) Replacing collection jar on emergent insect trap. Trap is suspended from bracket on the raft and not taken out of the water during transfer. (Photo by Dr. O. E. Kurt.)

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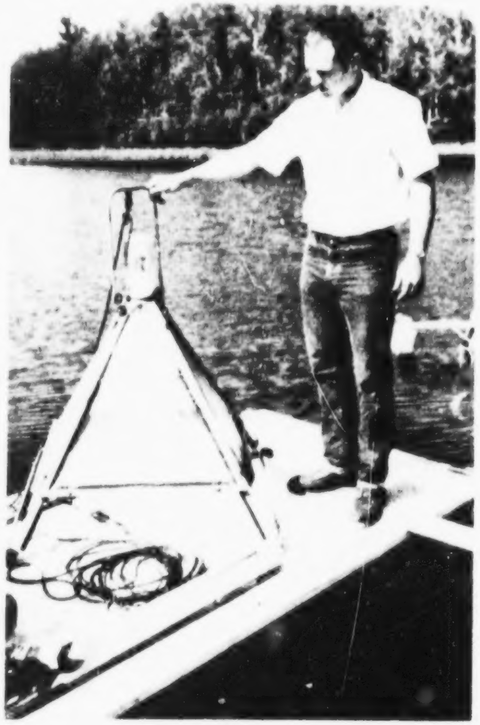

Fig. 7a

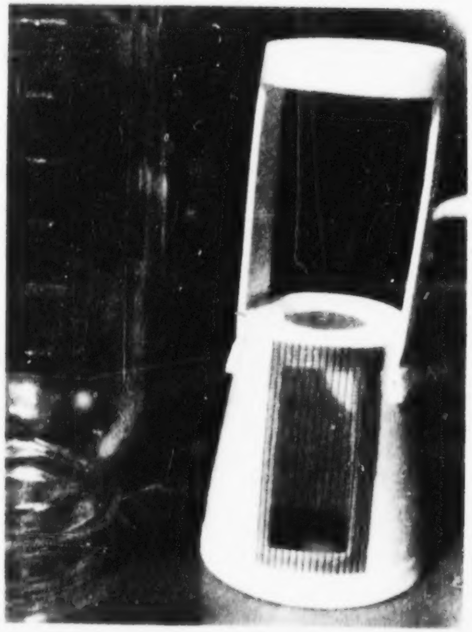

Fig. 7b

Fig. 7c

to the jar as needed to assure that the water level will be between the top of the first cup and bottom of the perch when the trap is in sampling position. The amount of water added will depend on sampling depth. At 20 meters, for example, no water is added beforehand since hydrostatic pressure will reduce the air space to 1/3 its surface volume. On the other hand, the shallow water bottles must have 2/3 their volume filled to assure an adequate level. As the deep water traps are lowered, water will flow into the bottle through the hole on the top, and the netting. As they are raised, the water will flow out these same apertures. If the netting were not present, the water would be forced to flow between the jar lip and the cup. The netting prevents this while retaining organisms and exuvia that are still in the water.

Five pair of insect traps were used in each lake; two at each of the same depth intervals indicated for the zoobenthos. The traps were used to collect insects five days each week. They were attended and moved daily, and allowed to dry out during the other two days each week to prevent insect attachment. The first day of each week the traps were placed in the water and suspended from the raft by a hook. The sample jar was added and the trap lowered to the bottom by a rope. The next day the trap was raised to the surface and again suspended from the hook while the sample jar was removed and another jar added (Figure 7 (c)).

The trap was then lowered to the same depth interval, but at a slightly different location. The body of the trap was not taken out of the water during the sampling period. It was not taken out for two reasons: (1) to prevent entrapment of insects on the surface of the lake in the trap. This was sometimes a problem during the first sampling period of each week. Aquatic and terrestial insects will accumulate on the lake's surface and be entrapped as the trap is lowered into the lake; and (2) it is more efficient and easier not to remove the trap. The collection jars were taken back to the laboratory where the insects were removed. At the laboratory, a small amount of tap water was added to the jar if needed and the jar was vigorously shaken to disorient the adult insects. The top and funnel were then removed and the water passed through a small fine mesh net into a white enamel tray. The funnel and jar were rinsed into the net. Insects and their exuvia were preserved in 90% ETOH vials for later identification and counting. Water was added to the jars as needed and the cap secured to be used for the next day's set of samples. Emergent insect samples were collected from June 15, 1969 through September 5, 1969 and from June 7, 1970 through September 4, 1970. Six hundred and 650 samples were collected from each lake during 1969 and 1970 respectively.

Rainbow Trout

One thousand right-pectoral fin clipped rainbow trout (RBT) were stocked in Section Four on June 6, 1969, and

1,002 right-pelvic fin clipped RBT were stocked in Hemlock on June 6, 1969. These fish were mostly one-year-olds raised at the Michigan Department of Natural Resources (DNR) trout rearing ponds at Wolverine, Michigan. Both lots averaged 7.3 inches (188 mm) fork length (Figures A-1 and A-2). The fish were released at one point on the shore of each lake. We measured each fish at the rearing ponds after they were anesthetized with MS-222. We observed only a few dead fish in each lake after their release.

One thousand seventy-one left-pelvic fin clipped RBT were released in Section Four on May 23, 1970. These fish were one-year-olds raised at the DNR's Wolverine rearing ponds. The fish averaged 7.9 inches (200 mm) fork length (Figure A-2). They were measured and handled the same as during 1969, except that they were sorted at Wolverine with wooden sorting trays. This was necessary to assure larger-sized fish than were stocked during 1969. Only a very few fish of less than 8.0 inches (215 mm) were captured by our gill nets. Two vertical gill nets similar to those described by Horak and Tanner (1964) were used in each lake (Figure 8 (a)). The stretched mesh sizes were 3.4 inch (19.0 mm) and 1.0 inch (25.4 mm). The nets were tied to the transect line at its deepest point (Figure 4). The nets were pulled once a day and the depth of capture and fin clip of each fish was determined (Figure 8 (b)).

The RBT stocked in Hemlock during 1970 were handled much differently than during 1969. About 2,000 one-year-olds

Figure 8. (a) Vertical gill net and roller. Gill net is suspended between raft pontoons as during sample collection process. (Photo by author.)

(b) Robert Hoffman removing fish from vertical gill net. (Photo by author.)

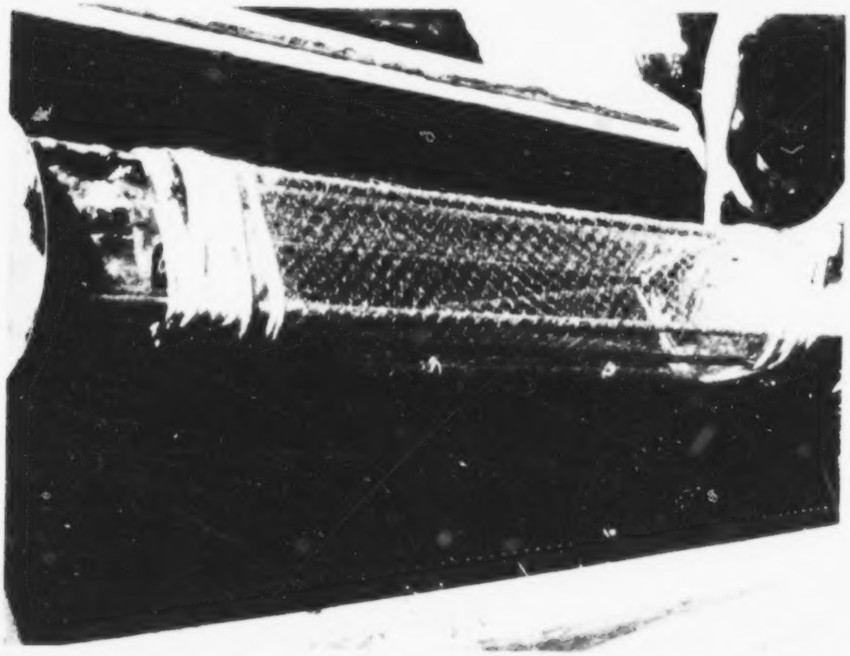

Fig. 8a

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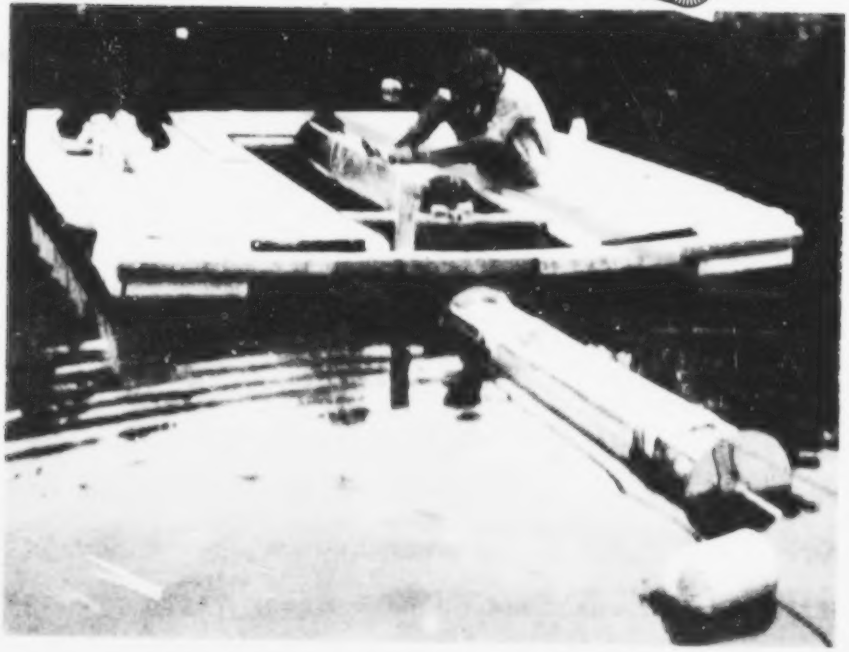

Fig. 8b

were transferred from the DNR's Wolverine rearing ponds to their hatchery at Grayling about June 1, 1970. These fish were sorted through wooden sorting trays at Wolverine. On June 25, 1970 these fish were divided into four lots of over 500 fish each. Each lot was measured as before and clipped with a different fin clip. These fish averaged 8.0 (203 mm) and 8.1 inches (206 mm) fork length (Figure A-1). The four lots were transported to Hemlock June 26, 1970 and each lot was put in a separate cage. The tops and bottoms of the cages were hexagons with each segment being 2.2 meters (Figure 9). One meter separated the top and bottom of each cage and they each contained 11.6 cubic meters of water. Two of the four cages were completely covered by wire and plastic, while the other two cages had only the top and bottom covered with plastic and wire and the sides were covered with aluminum window screen. One covered cage with the right-pectoral clipped fish was held at 3m depth (Figure 10). About 4,000 gallons/hour (15 m^3/hour) were pumped from 1 meter for the first day, and from 12 meters for the remainder of the acclimation period. The temperature within this cage was measured with a resistance thermometer and found to be the same temperatures as water at 12 meters. One screened cage with the anal-fin clipped fish was held at 3 meters depth. The other screened cage with the left pelvic clipped fish was lowered to 5 meter depth for one day and then to 12 meters. The other covered cage with the left

Figure 9. Acclimation cage used to hold rainbow trout at specific depths in Hemlock Lake. Rubber hoses led to water pumps on a raft. Cage is covered with polyethylene plastic and chicken wire. (Photo by author.)

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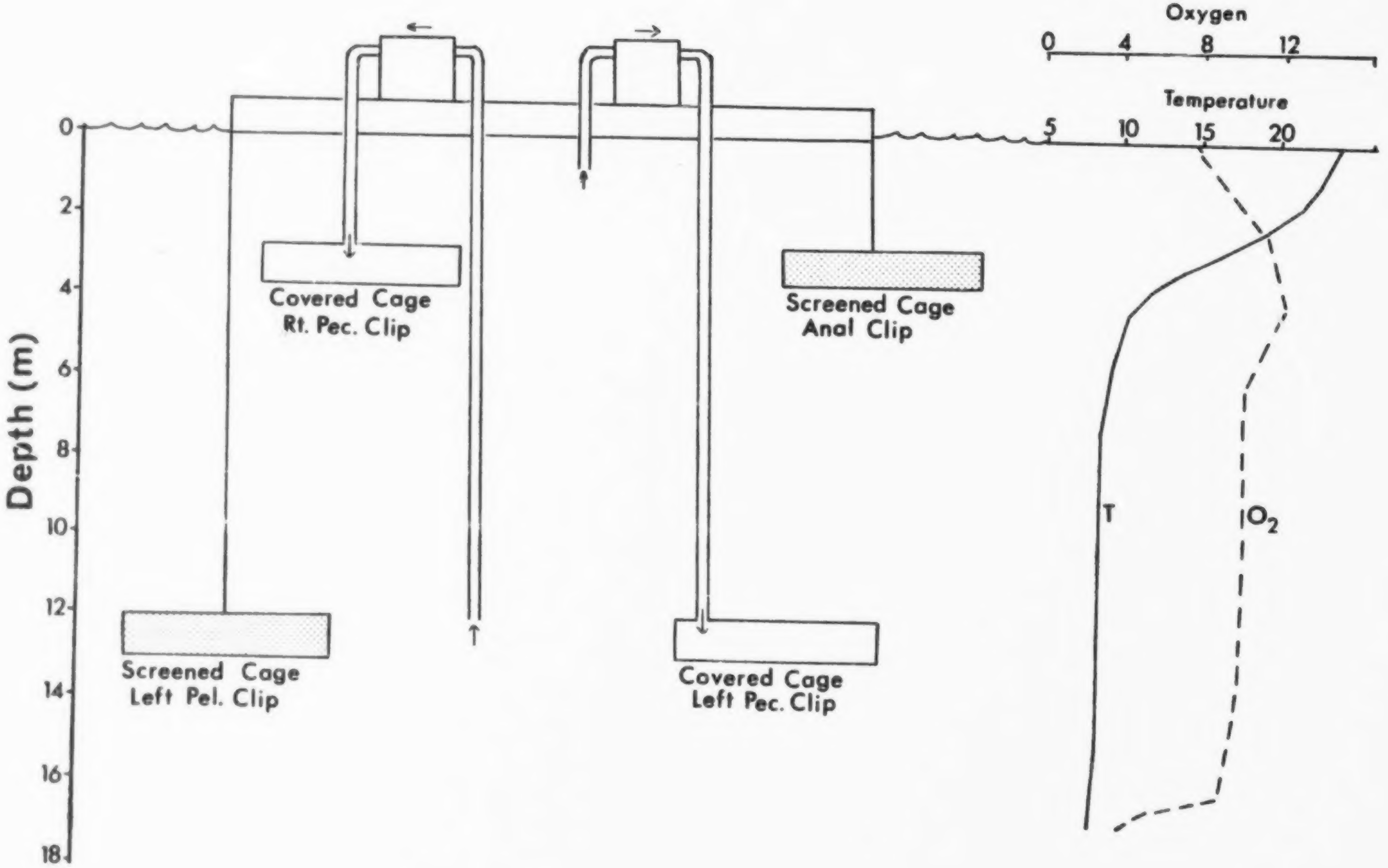
Figure 10. Configuration of Hemlock Lake acclimation cages. Fin clip of rainbow trout held in each cage is shown. The oxygen and temperature profiles during the acclimation period are also shown.


Oxygen
0
4
8
12
Temperature
5
10
15
20
T
O_2
Depth (m)
0
2
4
6
8
10
12
14
16
18
Covered Cage
Rt. Pec. Clip
Screened Cage
Anal Clip
Screened Cage
Left Pel. Clip
Covered Cage
Left Pec. Clip

pelvic clipped fish was lowered to 7 meters for one day and then to 12 meters. About 15 m^3/min. of water from one meter depth was pumped into this cage during the entire acclimation period. Water left the two cages through 5-inch diameter (127 mm) irrigation pipe. The pipes were screened to prevent fish passage. The pipe extended from 12 meters to 6 meters in the case of the 12 meter covered cage, and from 3 meters to 9 meters in the case of the 3 meter covered cage.

On July 1, 1970, the covered 3-meter cage and 12-meter cages were opened and left at their respective depths. Water was pumped into each covered cage as usual for another 8 hours. The 12-meter screened cage was opened at 12 meters and then floated to the surface. Over 200 RBT remained in the cage as it surfaced. The screened sides were then entirely removed, but the fish were reluctant to leave. Rather than open the screened surface cage at the surface as originally planned, I lowered this cage with the anal-fin clipped fish to 12 meters on July 1, 1970. They remained there until July 7, 1970 at which time I opened the cage at the 12-meter depth and left it there.

A few left-pectoral and left-pelvic fish were caught in the gill nets between June 25th and July 1st. These fish may have escaped from the cages, or escaped when the fish were being placed in the cages from the planter truck. The cages were later inspected but no obvious openings were present. The length, weight and scale samples were recorded for each fish collected in the gill nets, and gross estimates of their stomach contents were made.

Only a few dead fish were observed in Hemlock following stocking during 1970 but 15 dead fish were observed in Section Four after they were released in May.

Statistics

All confidence estimates placed on means, or totals were computed using the appropriate t and standard error values. Non-homogeneous and non-rectifiable variances negated the use of analysis of variance tests and other parametric statistics. For these reasons these tests were not applied. The graphical method (Dice and Leraas, 1936) is used to compare appropriate means in many cases. Most of the calculations were performed on Michigan State University's CDC 3600 computer. Most figures were drawn using this computer and their CalComp plotter.

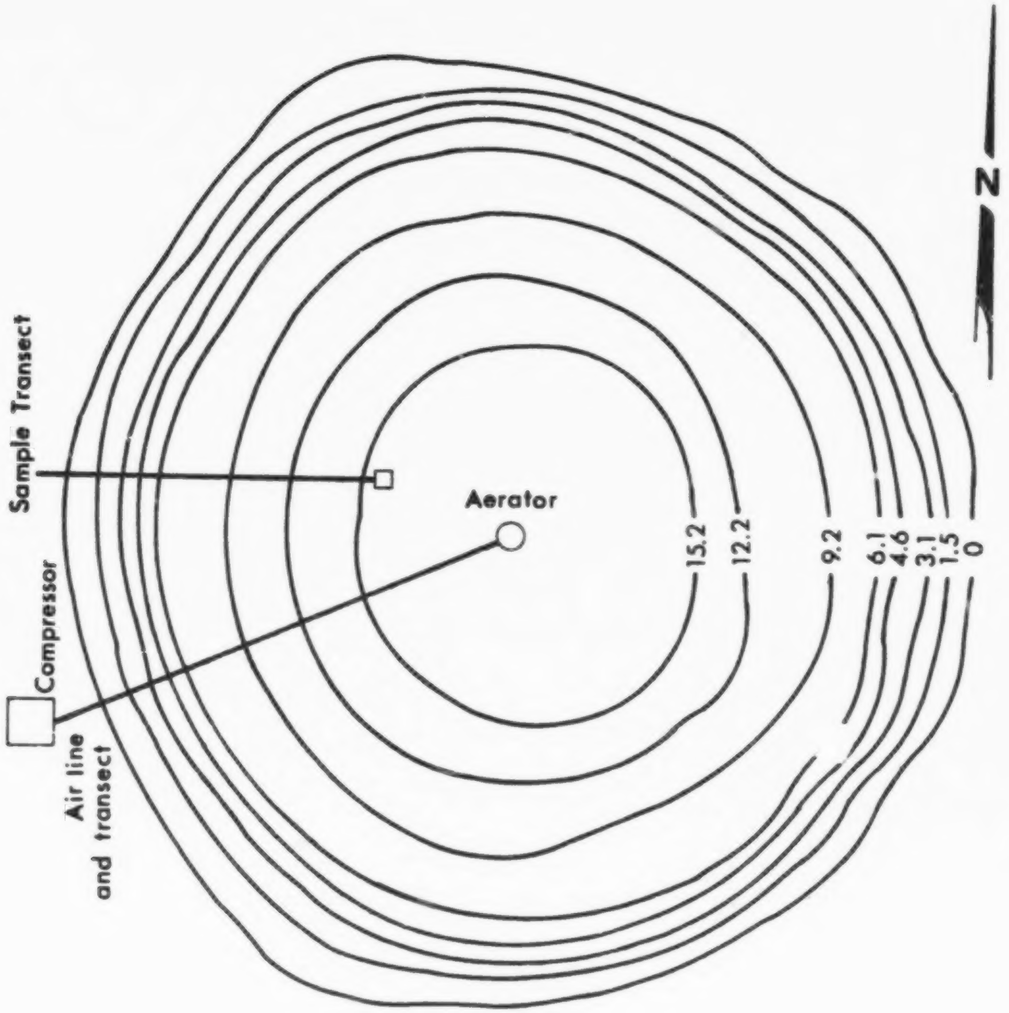
DESCRIPTION OF THE LAKES

Hemlock and Section Four lakes are located in the Pigeon River State Forest, about 85 km south of the Straits of Mackinac. The Pigeon River Trout Research Area includes these lakes, four other lakes and 8.7 mg of the Pigeon River, and has special use restrictions. All the lakes were closed to public angling and certain other activities during our study. Hemlock Lake is in Cheboygan County and Section Four is in Otsego County. These two lakes are only 3 km apart, but possess much different properties.

Earlier observers (Eschmeyer, 1938) thought these lakes were glacial pit lakes (Scott, 1921), but later evidence indicates they are actually lime sinks (Tanner, 1952, 1960). This latter hypothesis was partly substantiated when the west shore of Section Four collapsed during May 1950. The lakes are apparently enlarging in this manner, and scalloping of their margins is evident from aerial observation (R. C. Ball, personal communication).

The lakes are nearly circular in outline with concentric depth contours (Figures 11 and 12). Although not shown on Hemlock's contour map, a marshy area is situated just north of and confluent to the lake. This area is in direct contact

Figure 11. Contour map of Hemlock Lake showing sample transects and aerator. Depth intervals are in meters.


N
Sample Transect
Compressor
Air line and transect
Aerator
15.2
12.2
9.2
6.1
4.6
3.1
1.5
0

Hemlock Lake

Scale: 25.6 mm = 30.0 meters

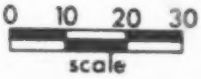
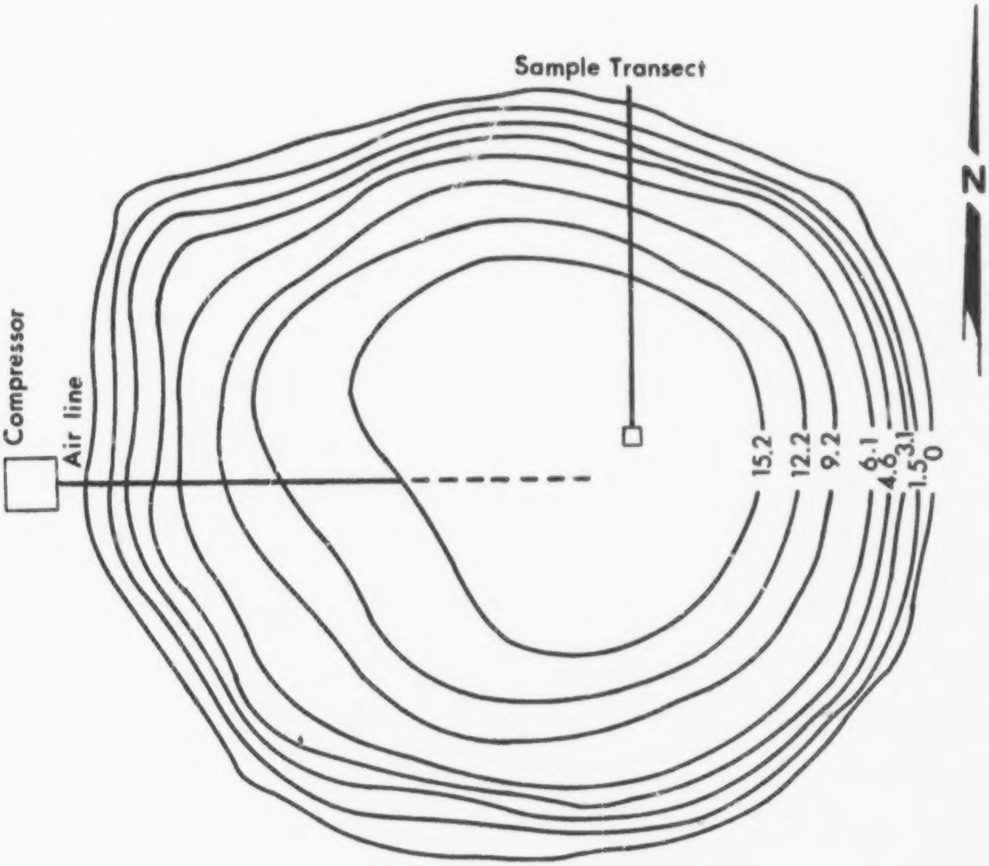
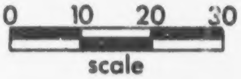

0
10
20
30
scale

Figure 12. Contour map of Section Four Lake showing sample transect and air line. Air was released from the dashed section of the air line. Depth intervals are in meters.


Sample Transect
N
Compressor
Air line
15.2
12.2
9.2
6.1
4.6
3.1
1.5
0

Section Four Lake

Scale: 31.6 mm = 30.0 meters


0
10
20
30
scale

with the lake, but contains only a few inches of water. Very dense vegetation undoubtedly restricts communication between the lake and the marsh.

Tanner (1952) indicates that during his September 1950 surveys of the lakes Hemlock had a maximum depth of 19.5 meters and surface area of 2.4 hectares, whereas Section Four was 22.8 meters and 1.0 hectares. Based on the 1957 surveys and my depth soundings during January 1970, Hemlock was 18.6 meters maximum depth and 1.8 hectares, while Section Four was 19.1 meters and 1.2 hectares. My Hemlock surface area value does not include the marsh area to the north of the lake. The 1957 surveys measured 18.1 meters maximum depth in both lakes. These data indicate that Hemlock water level has been relatively stable, but Section Four's has changed as much as 4.6 meters between 1950 and 1957. This change may have been due in part to the basin collapse during May 1950 (Tanner, 1952). The collapse could have caused greater siltation of the basin, or increased seepage from the basin. Tanner's September 1950 lake survey did not indicate an immediate depth change due to the collapse.

Section Four's water level was stable during the summer 1969, fluctuating only a few centimeters. Its early summer 1970 level was within a few centimeters of the 1969 level, but decreased about 0.3 meters by the end of the summer. The greatest rate of decrease occurred during August 1970. Hemlock's water level was very stable both summers and fluctuated only a few centimeters during the study period.

Although both lakes are designated marl lakes, they differ greatly. Section Four is a typical marl lake. It is oligotrophic with plentiful oxygen at all depths all year. During 1969-70 Chara spp. was found at all depths. It was sparse in the shallow depths, but formed large beds in deeper water. Other rooted plants were sparse except at the shoreline. Phytoplankton was very sparse, with the result that secchi disc transparencies often exceeded 12 meters. On August 11, 1969, more than 15% of the surface irradiance was still present at 12 meters (Figure 13). Secchi disc was 10.25 meters on this date. The water had the greenish-blue coloration typical of marl lakes.

Section Four's sediments are mostly calcarious. They range between 1.2% and 12.2% as $CaCO_3$-C on a dry weight basis (Figure 14). Organic carbon ranges between 0.0% and 6.4%. The profundal sediment measured 3.4% organic carbon and agrees well with Barrett's (1952) post-collapse data. Before the collapse of the west shore during May 1950, Section Four's profundal sediments average 41.2% as organic matter. After the collapse they averaged 6.2%. This indicates that the profundal sediments were blanketed with a layer of sand and silt which in effect sealed in the rich organic matter. This occurrence is also evidenced by changes in the phosphorus content of Section Four's profundal sediments. These sediments averaged 37.2 mg PO_4/kg air-dry soil before the collapse, but only 1.7 mg/kg after. The removal

Figure 13. Hemlock and Section Four relative irradiance measurements on August 11, 1969.

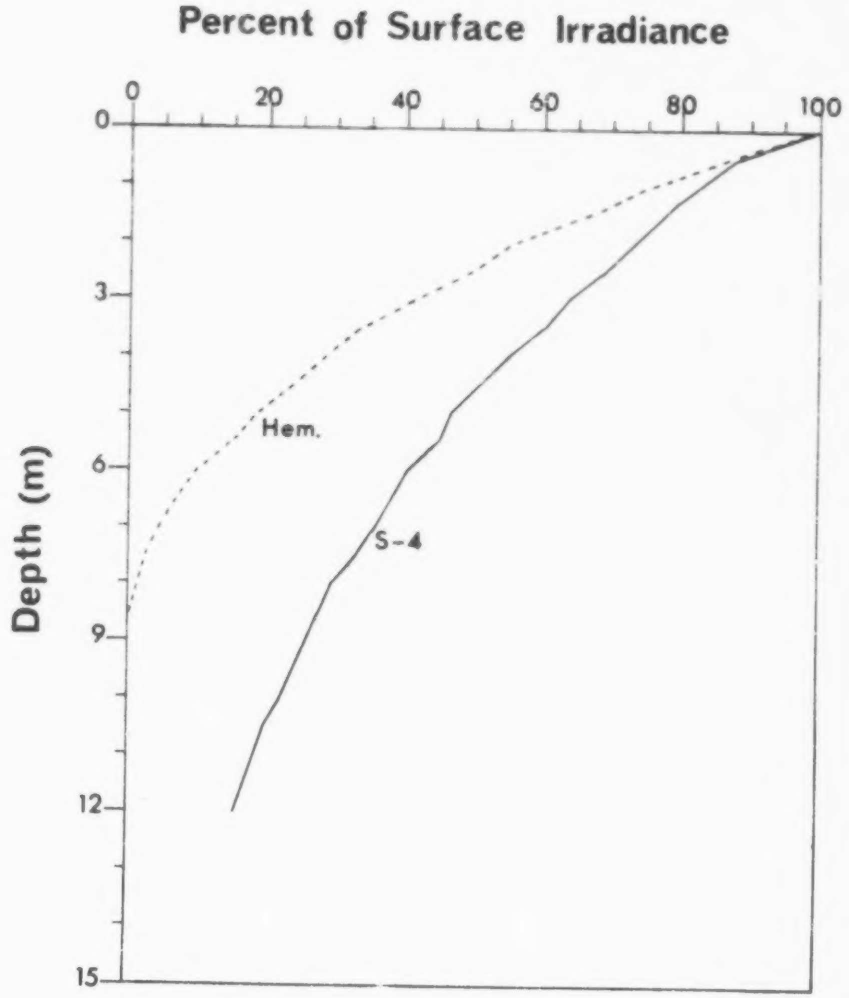
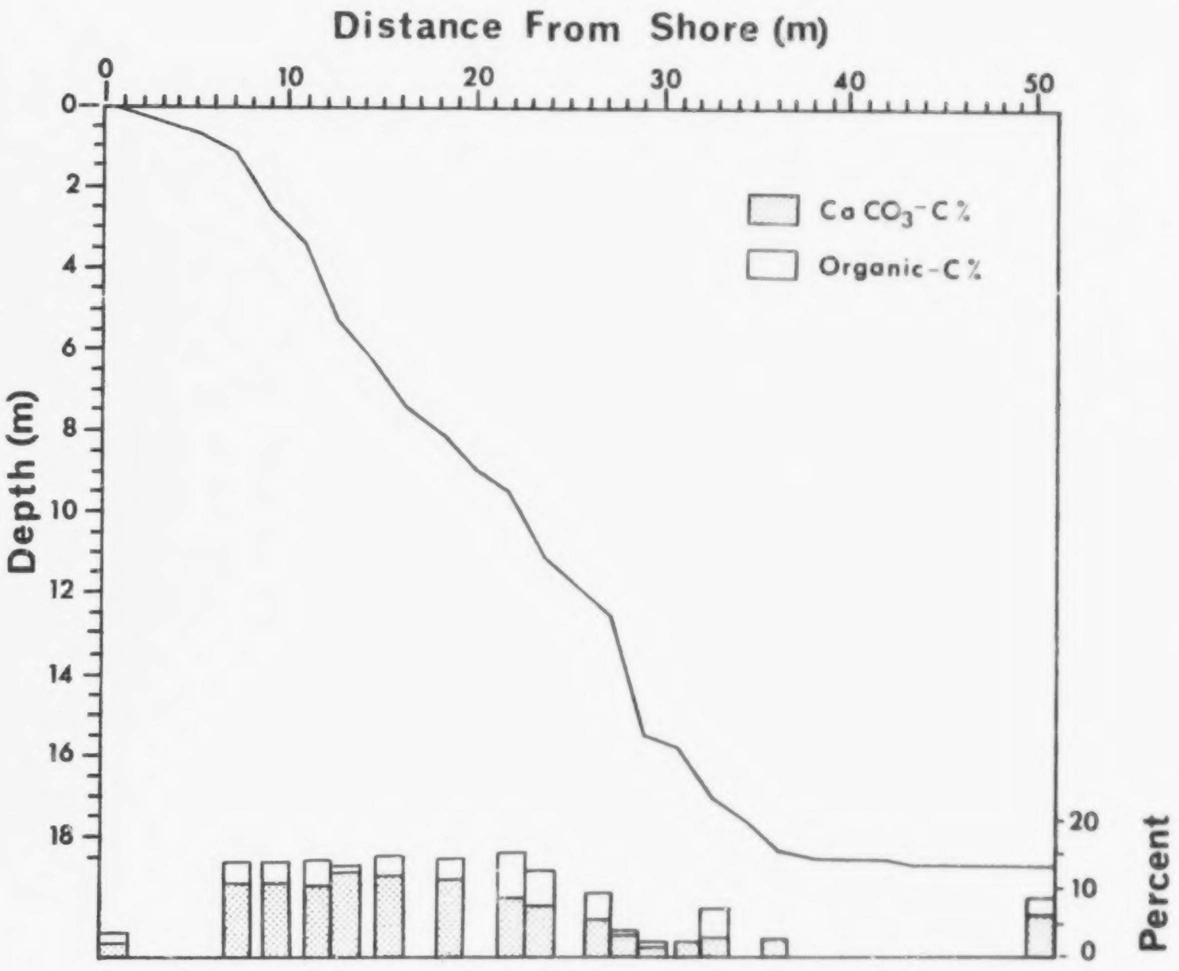

Percent of Surface Irradiance
0
20
40
60
80
100
0
3
6
9
12
15
Depth (m)
Hem.
S-4

Figure 14. Section Four transect profile illustrating percent organic carbon and percent $CaCO_3$-carbon at different depths.


Distance From Shore (m)
0
10
20
30
40
50
Depth (m)
0
2
4
6
8
10
12
14
16
18
Ca CO$_3$-C %
Organic-C %
Percent
20
10
0

19

of this nutrient-rich material from the lake ecosystem should decrease productivity. This was not immediately evident following the collapse because of artificial fertilization during 1949 and 1950 (Tanner, 1952). Long-term comparisons indicate productivity has decreased. Survey data from August 1932 (Table 1) indicates a sharp oxygen reduction below the metalimnion, approaching zero at the bottom. Carbon dioxide and total alkalinity increased markedly below this depth. Secchi disc was only 6.8 meters. During August 1969, oxygen values were more than 4.5 mg/l at all depths. Carbon dioxide was less than 8 mg/l and alkalinity was not stratified. Secchi depths were generally greater than 10 meters. These comparisons indicate that primary productivity decreased as a result of the basin collapse and organic profundal sediments entrapment.

Hemlock Lake is not a typical marl lake. Although it is highly alkaline, and has marl deposits in shallow water, these sediments are covered with a thick layer of peaty organic material. The organic material originated mostly from the surrounding forest and the marsh bordering the lake. It is very loosely compacted in shallow water, but gelatinous in deep water. These profundal sediments float to the lake's surface when broken loose from the bottom by sampling gear. The surrounding forest contains mostly deciduous species which shed much of their leaves into Hemlock Lake. Tree leaf remains are evident in the profundal sediment.

Table 1 . Section Four Lake limnological data collected August 1, 1932 by the Institute for Fisheries Research, Michigan Department of Natural Resources. Secchi disc depth was 6.8 meters on this date.

Depth (m)	Temp. (°C)	Oxygen	Free CO_2	pH	Total Alkalinity
0	24.4	9.1	0.0	7.9	154
1	22.8	--	--	--	--
2	22.5	--	--	--	--
3	22.2	--	--	--	--
4	21.7	--	--	--	--
5	20.6	--	--	--	--
6	16.1	--	--	--	--
7	13.3	--	--	--	--
8	12.2	11.1	4.0	7.6	174
9	11.1	--	--	--	--
10	9.4	--	--	--	--
11	8.3	--	--	--	--
12	7.8	--	--	--	--
13	7.2	--	--	--	--
14	6.7	1.8	13.9	7.3	187
15	6.1	--	--	--	--
16	6.0	--	--	--	--
17	5.6	--	--	--	--
18	5.6	--	--	--	--
19	5.6	--	--	--	--
20	5.2	--	--	--	--
21	5.0	Trace	22.0	7.2	198
22	5.0	--	--	--	--

Section Four Lake, on the other hand, is surrounded mostly by evergreens. Hemlock's sediments range from 0.0% to 43.1% as organic carbon, and from 0.0% to 26.1% as $CaCO_3$ carbon (Figure 15). During 1949-50 Hemlock's profundal sediments averaged 53% as organic matter, compared to 43% for 1968-69 (Barrett, 1952). This difference is probably due to analytical and sampling differences rather than changes in the sediment.

Unlike Section Four, Hemlock Lake is eutrophic and meromictic. Prior to aeration, the bottom few meters were amictic and formed a monimolimnion that did not circulate following spring and fall turnovers. This zone was anoxic and contained high concentrations of carbon dioxide and other gases. Water samples drawn from this depth effervesced due to the release of dissolved gases. These gases were held in solution by hydrostatic pressure. Carbon dioxide, alkalinity, and conductivity values increased sharply in this zone (Figure 16). Oxygen values were always 0.0 mg/l and pH was about 6.6. A small unidentified bacterium (Brian Moss, personal communication), was very abundant in this zone and was apparently responsible for the greenish tint of the monimolimnion water. Fine green needles appeared suspended in the water. Abundant filamentous algae or bacteria have often been found in the monimolimnion of other meromictic lakes. Hemlock's meromixis developed after 1932, since survey data collected during July 1932 indicate no monimolimnion (Table 2).

Figure 15. Hemlock transect profile illustrating percent organic carbon and percent $CaCO_3$-carbon at different depths.

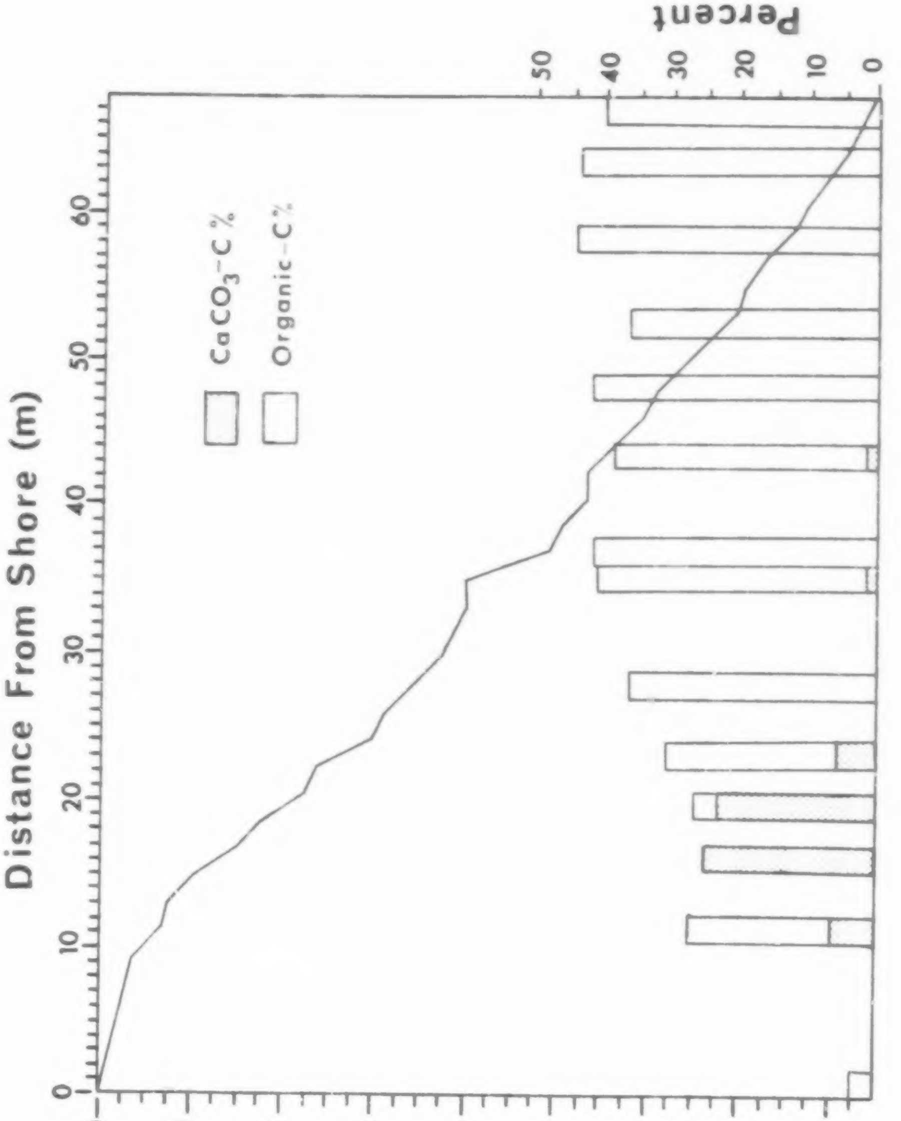

Distance From Shore (m)
0
10
20
30
40
50
60
Depth (m)
0
2
4
6
8
10
12
14
16
Percent
0
10
20
30
40
50
$CaCO_3$–C %
Organic–C %

Figure 16. Hemlock Lake carbon dioxide alkalinity, pH and conductivity profiles on August 13, 1969. This is representative of pre-aeration condition. Chemocline of monimolimnion is evident below 12 meters.

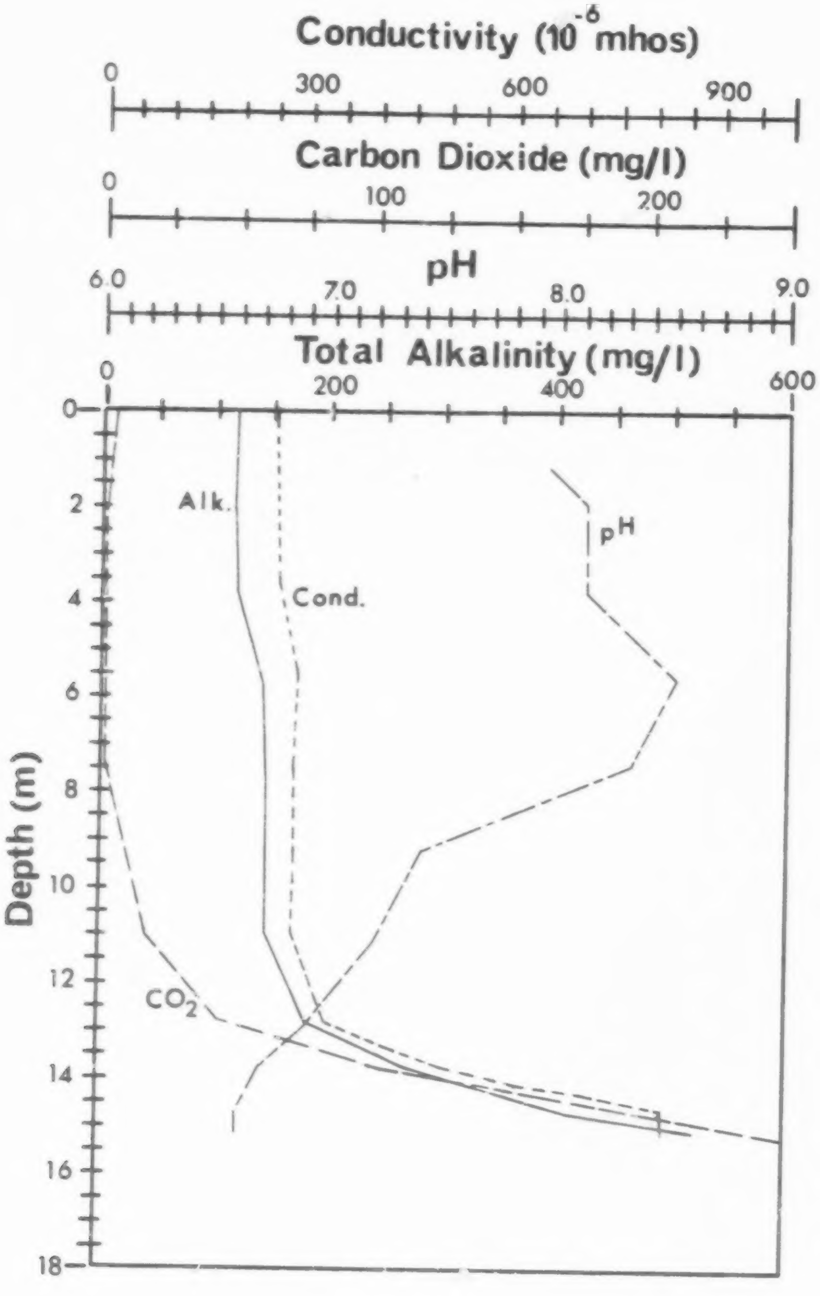

Conductivity (10^{-6} mhos)
0
300
600
900
Carbon Dioxide (mg/l)
0
100
200
pH
6.0
7.0
8.0
9.0
Total Alkalinity (mg/l)
0
200
400
600
Depth (m)
0
2
4
6
8
10
12
14
16
18
Alk.
Cond.
pH
CO$_2$

Table 2 . Hemlock Lake limnological data collected July 28, 1932 by the Institute for Fisheries Research, Michigan Department of Natural Resources. Secchi disc depth was 4.2 meters on this date.

Depth (m)	Temp. (^{o}C)	Oxygen	Free CO_2	pH	Total Alkalinity
0	21.1	8.7	10	8.1	160
1	20.6	--	--	--	--
2	20.6	--	--	--	--
3	20.0	--	--	--	--
4	19.4	--	--	--	--
5	14.4	--	--	--	--
6	13.3	--	--	--	--
7	10.0	--	--	--	--
8	6.7	--	--	--	--
9	6.7	--	--	--	--
10	6.1	6.0	12	8.0	156
11	6.1	--	--	--	--
12	6.1	--	--	--	--
13	6.1	--	--	--	--
14	6.1	--	--	--	--
15	5.6	--	--	--	--
16	5.6	--	--	--	--
17	5.6	--	--	--	--
18	5.6	--	--	--	--
19	5.6	2.3	39	7.4	198

Oxygen was 2.3 mg/l at the bottom compared to zero during 1969. Carbon dioxide and alkalinity increased below 10 meters, but not dramatically. pH was 7.4 at the bottom compared to 6.6 during 1969. The 4.2 meter secchi disc reading is comparable to 1969 values.

Due to its organic richness, Hemlock secchi disc transparency seldom read more than five meters prior to aeration. On August 11, 1969 less than 1% of surface irradiance was still present at 9 meters (Figure 13). Secchi disc was 6.25 meters on this date. The water supported abundant phytoplankton and zooplankton standing crops. Submergent aquatic plants were very sparse, while emergents were abundant only along the shore and in the marsh.

During 1969-70, Hemlock Lake contained bluntnose minnows (*Pimephales notatus*) and redside dace (*Gila elongata*). Both species were abundant and reproduce in the lake. They are primarily littoral in habit, but are sometimes found in open water near floating objects. Neither apparently inhabit depths greater than a few meters, even when the lake is isothermal. One brook trout (*Salvelinus fontinalis*) was caught on the first net set in 1969, but none were found thereafter.

Section Four Lake contained a residual population of rainbow trout at the time my study began, but no other fish species. These fish were stocked during 1964 and 1965. Three thousand trout, at 2,200/kg, were stocked each year (Carl Latta, personal communication). These fish averaged about 33 cm FL during 1969-70, but were very emaciated.

They typically had disproportionately large heads and "slab" sides. The lack of abundant, large zooplankters or other desirable forage undoubtedly accounts for their condition. They fed almost exclusively on adult insects that fell on the lake's surface. Detritus and benthic filamentous algae were often present in their stomachs. They very seldom fed on crayfish or zoobenthos, although both were relatively abundant. Trout mature sexually, but do not reproduce in either Hemlock or Section Four lakes.

Tanner (1952, 1960), Barrett (1952) and Siler (1968) describe in greater detail the history and artificial fertilization of these lakes. Both lakes were fertilized during 1949 and 1950. Their productivities were greatly increased and they became more eutrophic. They apparently returned to their prefertilization conditions by 1967, however.

HEMLOCK LAKE

Hypolimnion Aerator

The aerator used in Hemlock Lake is a new design. It differs significantly from one used by Bernhardt (1967) and one designed by R. E. Speece (Fast, 1968). It is only the second hypolimnion aerator to ever have been used successfully.

The aerator free-floats in the center of the lake (Figures 17 and 18). Styrofoam and steel barred floats suspend it off the bottom, and air is delivered through a 38 mm I.D. plastic pipe from a shore compressor. The aerator is held in place by four anchors and ropes. The aerator was partly fabricated by Armco Steel Corporation at their Indiana plant. It was trucked to Hemlock Lake where it was unloaded onto a wooden cradle (Figure 19 (a)). The 3.1 m section that extends above the lake's surface was then banded to the lower section. The wooden cradle provided support for the aerator while the floats and hardware were attached, and made it easier to slide the aerator into the lake. The cradle rested on 27 round wooden posts. The post, in turn, rested on two wooden "rails" that ran into the lake. After the floats and hardware were attached, the aerator rolled down

Figure 17. Cross-sectional view of Hemlock Lake hypolimnion aerator. Dotted lines represent projected edges. Tower is tilted toward the viewer, and parts are drawn approximately to scale.

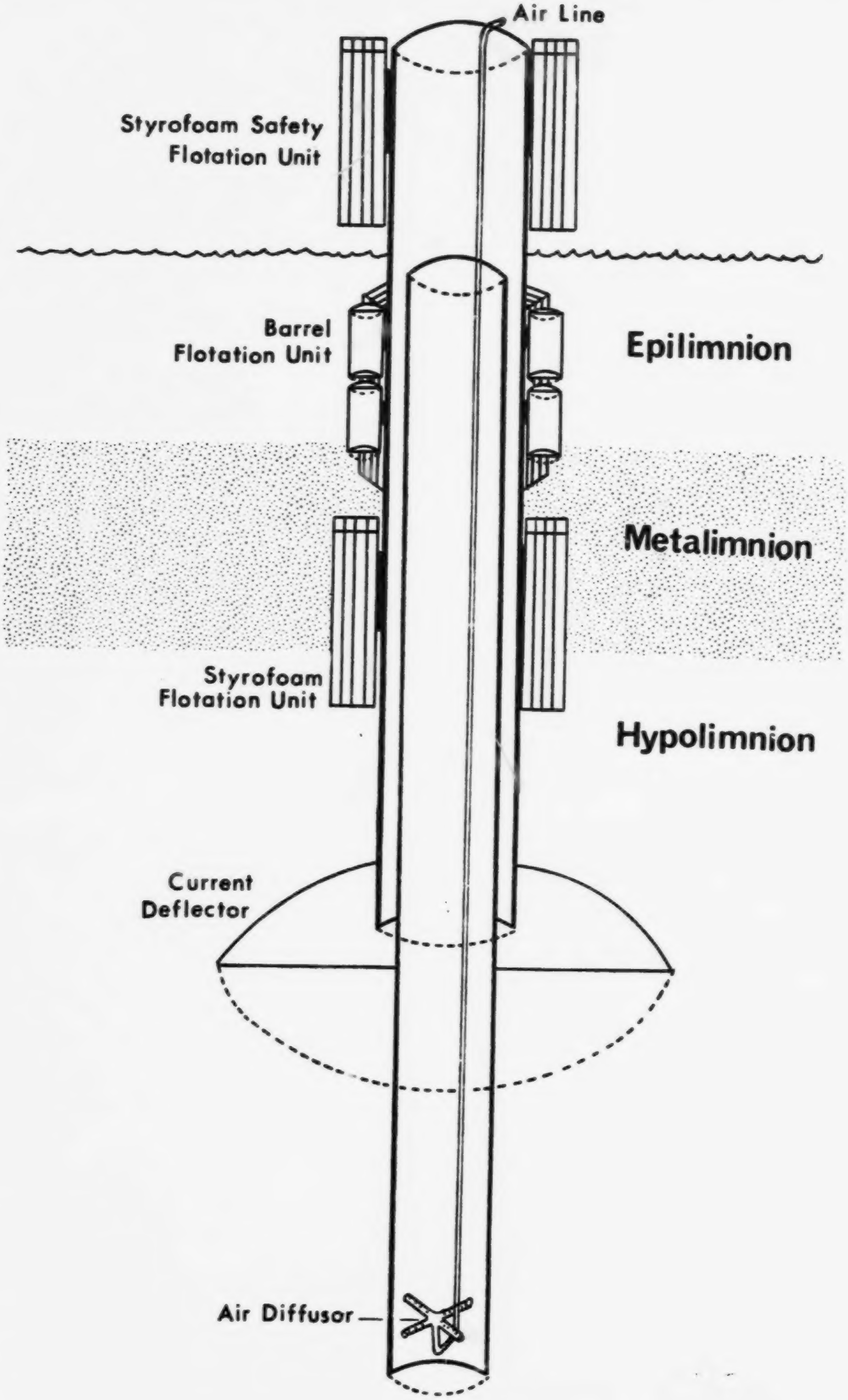

Air Line
Styrofoam Safety Flotation Unit
Barrel Flotation Unit
Epilimnion
Metalimnion
Styrofoam Flotation Unit
Hypolimnion
Current Deflector
Air Diffusor

Figure 18. Hemlock hypolimnion aerator in operating position. Only the upper three meters are visible. Air supply line enters the scene from the left. Above water styrofoam flotation units are a safety feature to prevent tower from sinking if submerged units should fail. Ladder on side of aerator permits access to top of tube. (Photo by author.)

Reproduced from best available copy.

Figure 19. (a) Arrival of Hemlock hypolimnion aerator tubes from the factory. Top three meters section of aerator is separated and located next to the truck cab. The tower was unloaded on the wooden cradle and logs in the foreground and fittings were attached before it was shoved in the lake. (Photo by author.)

(b) Hemlock hypolimnion aerator floating horizontally. Temporary floats kept the lower end up while the current deflector was attached. The lower end is closest to the viewer. Deflectors could not be added until the aerator was floating horizontally in the lake. (Photo by author.)

(c) Hemlock hypolimnion aerator tilting into sampling position. The temporary floats have just been removed by the author using SCUBA. (Photo by Robert Hoffman.)

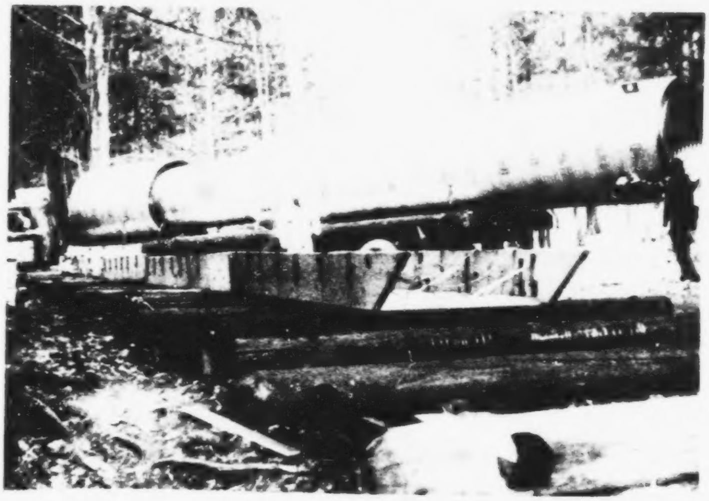
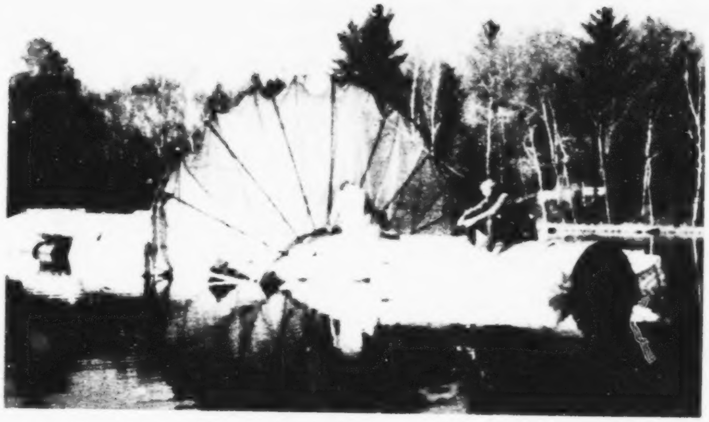


Fig. 19a



Reproduced from best available copy.

Fig. 19b

Fig. 19c

the rails on the posts and into the lake. Temporary styrofoam floats were attached to the bottom of the tower so the tower floated horizontal in the water (Figure 19 (b)). This was necessary since the current deflector had to be attached after the tower was in the lake. After the current deflector was attached, the temporary floats were cut loose and the tower swung into its vertical operating position (Figure 19 (c)).

Description. The aerator consists of two corrugated, 14-guage, galvanized iron tubes (Figure 17). One 1.85 meters diameter tube extends 3.1 meters above the lake surface, to 9.2 meters below the surface. The other 1.38 meters diameter tube is partly located inside the larger tube and extends from the lake's surface to the 15.5 meters depth. The smaller tube is attached to, and positioned within the larger tube by eight 13 mm x 0.31 m x 0.49 m iron plates. These plates are welded to the outside of the smaller tube, extend through slots cut in the larger tube and are also welded to the larger tube around the slot (Figure 20). Four plates are thus located near the top of the small tube and four near the bottom of the large tube. The plates are spaced 90° apart around the circumference of the tubes at each site and are positioned with their long axis vertical.

A current deflector is attached to the small tube by clamps and is located one meter below the bottom of the large tube (Figures 17, 19 (b) and 21). It is 6.3 meters in

Figure 20. Cross-sectional view and parts of hypolimnion aerator.

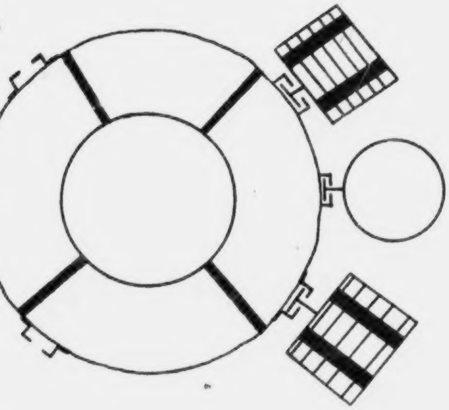
A. Cross-section of aerator taken near the top. Two styrofoam flotation units and one barrel flotation unit are shown.

B. Styrofoam flotation unit.

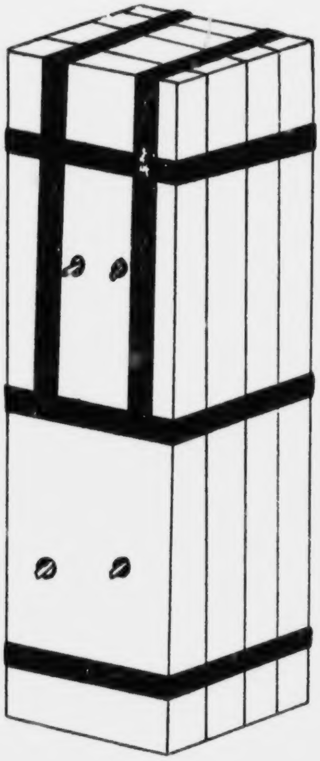
C. Barrel flotation unit showing the tee structure used to attach it to the aerator.

D. Cross-section of tee inside the slot structure. The slot is welded to the outside of the aerator.

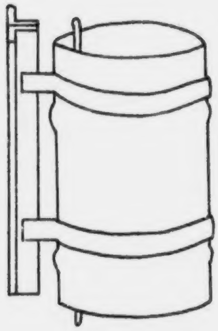
A



B



C



D

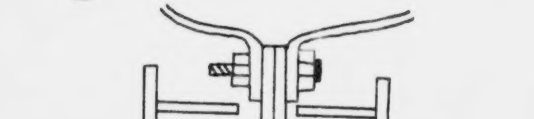


Figure 21. Hemlock hypolimnion aerator current deflector before they were attached to the aerator. Anchors in foreground were used to anchor the tower in its operating position. (Photo by Ed Schultz.)

diameter. The deflector was constructed in halves. Each half has a central axis of 14 guage corrugated iron. The iron is curved with the same radius as the small tube and is 0.31 m wide. Seven 13 mm I.D. pipes are welded perpendicular to the axis. These pipes are 2.5 meters long. A 6 mm x 51 mm piece of flat iron is welded to the ends of the pipes to form a large semi-circular rim of radius 3.15 m. Two additional 2.5 m length of flat iron extend from the axis to the outer flat iron rim. Galvanized fencing (2 cm x 2 cm holes) is wired to the pipes and flat iron. A nylon parachute covers the top of the fencing and is drawn tight about the axis. Chicken wire (6 cm diameter holes) covers the parachute and holds it firmly against the fencing.

The aerator is free-floating. It is buoyed up by six styrofoam flotation units and four 220 liter steel drums (Figures 19 (b) and 20). Each drum has a 12 mm aperture on its bottom that is open to the water. A 3 mm copper tube and globe valve extends from the top of the drum to above the water level. Air may thus be let out of the drum by opening the valve. The buoying of the aerator is thus adjusted with these drums. Each styrofoam flotation unit consists of four 0.15 m x 0.46 m x 2.5 m pieces of styroform (Figure 22 (a)). These are sandwiched between two pieces of 19 mm marine plywood and banded by 6 mm x 51 mm flat iron strips. Both barrel and styrofoam units are attached to the aerator via a 6 mm thick, 51 mm x 38 mm iron tee (Figures 20 and 22 (a)). The tee is 1.8 m long and slides into an iron

Figure 22. (a) Styrofoam flotation unit used on the Hemlock Lake hypolimnion aerator. The tee structure used to attach the unit to the aerator is shown on top. (Photo by author.)

(b) Slots for flotation unit tee's being welded on the side of the aeration tower. The iron plates used to position the inner tube are shown projecting through the outer tube to the left of the workmen. (Photo by author.)

(c) Sliding styrofoam flotation unit into slot on side of aeration tower. Logs and "runway" are shown leading into the lake. (Photo by Ed Schultz.)

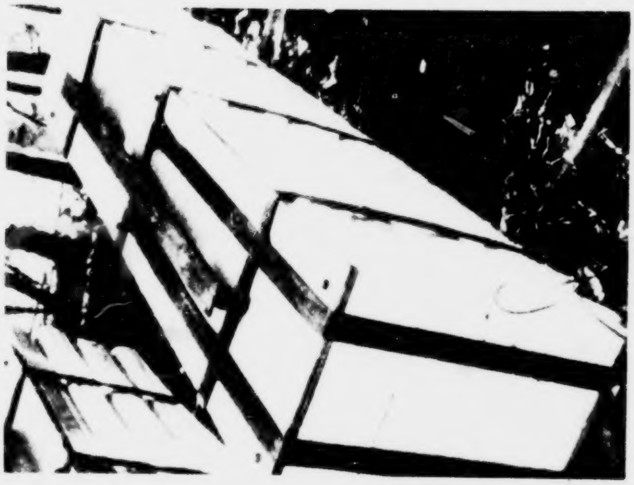


Fig. 22a

Fig. 22b

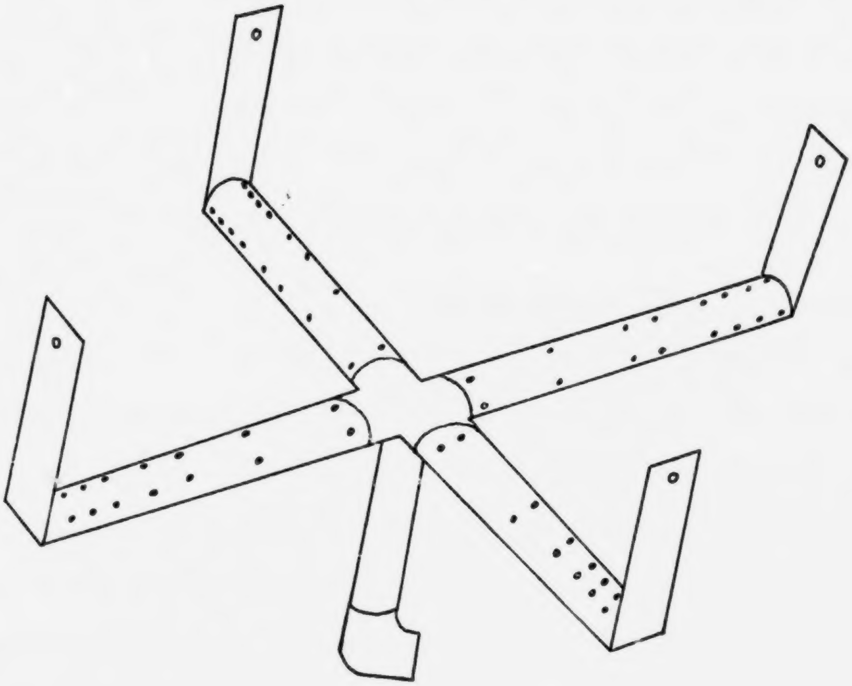
Fig. 22c

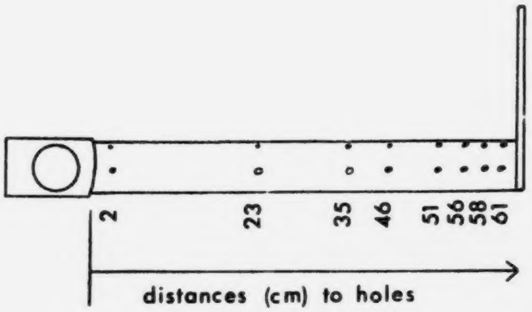
slot welded to the side of the large tube (Figures 22 (b) and 22 (c)).

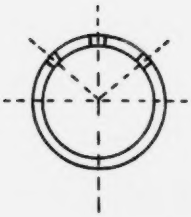
Not shown in Figure 17 are two small styrofoam units that were attached on opposite sides of the tower to the lower steel plates that connect the inner and outer tubes. These floats are attached with block and tackle to the portion of the plate that extends through the outer tube. These styrofoam units were used to adjust the vertical position of the tower in the water. Also not shown in Figure 17 is a 220-liter steel drum filled with cement and attached near the bottom of the tower. This was added after the tower was in its operating position and I discovered there was too much buoyancy. Parts of the submerged styrofoam units were cut away using SCUBA to further reduce buoyancy.

Air was released from an air diffusor located one meter from the bottom of the aerator (Figure 23). A PVC plastic, 38 mm-diameter air line passed over the top rim of the aerator and down to the diffusor. The air line was fastened to the walls of the aerator with clamps and sheet metal screws. The diffusor consisted of four 61 cm long, 38 mm diameter steel pipes joined by a side-armed cross fixture. Four 6.8 mm x 58.8 mm x 30 cm pieces of flat iron were welded over the outer ends of the pipes. A hole was drilled in each piece of flat iron and a bolt used to fasten them to the walls of the aerator. Each of the four diffusor arms contained 24 3.18 mm diameter holes. Eight sets of holes were

Figure 23. Air diffusor used on the hypolimnion aerator. The hole site spacings along one arm are shown. Three holes were drilled at each site as shown in the cross-sectional view of one arm.




distances (cm) to holes



unevenly spaced along each arm. At each site, one hole was drilled on the top of the pipe, while the other two were drilled on opposite sides, 45° from the top. The holes were spaced in this manner to assure an even distribution of air and to impart an upward thrust to the water.

Compressor. A Jenbach air-cooled JW 156 diesel compressor supplied air to the tower during the summer 1970. The compressor had three set speeds: (a) 1500 rpm delivering 147 cfm at 100 psi; (b) 1200 rpm delivering 125 cfm at 100 psi; and (c) 1000 rpm delivering 100 cfm at 100 psi. The pressure in the system was only about 28 psi. An 8,000 liter fuel tank was connected to the compressor. The compressor used less than 4 liters of diesel fuel per hour at 1500 rpm.

During January 1971, I used a Jaeger air compressor. This has a maximum air output of 75 cfm at 100 psi. It ran at about two-thirds maximum capacity. This is a very rough estimate since we did not measure air output.

Operation. I began aerating June 13, 1970, but only ran the compressor for 10 minutes. A great deal of water and air leaked through the tower, especially where the two sections were banded. The tower was then raised so that the inner tube was 0.5 m above the water level and we plugged some of the holes with an epoxy material. The epoxy hardened overnight. June 14th we resumed air injection. The tower was kept at its elevated position and the compressor run at

1000 rpm. Water rose in the inner tube and cascaded over one side of the tube. The tower tilted at an 80° angle to the lake surface. We tried to correct the tilt with floats, but without success. Air rising in the tower displaces water and decreases the specific density of the tower-water system. Water is also elevated 0.5 m above the lake level within the tower. The center of gravity is thus raised and the tower tilts. This condition could be corrected with proper anchoring, and/or addition of ballast.

Water and air continued to leak through the tower, although less than before. This was due in part to the tilt of the tower, but in larger part to improper construction of the culvert tubes. The tubes are constructed of galvanized iron plates. The plates were bent and riveted together. Caulking should have been applied between the plates before they were fastened, but was not.

June 17, 1970 the tower was lowered 0.5 meters and the compressor run at 1500 rpm. The compressor was always run continuously, except when shut down for maintenance or repair. The aerator was run in this manner until July 15th. At this time it was lowered another 0.5 meters and run at 1000 rpm. This schedule was maintained until September 7th, at which time operation was discontinued.

I injected air through the aeration tower for 48 continuous hours beginning January 22, 1971. The tower was in its lowermost position, such that the inner tube was 0.5 m below the lake's surface level. Holes were chopped in the ice inside the aerator to vent the air. All the ice in the tower melted quickly after aeration began.

Aeration Efficiencies. We wished to determine the most efficient means of aerating, in terms of air input, as well as the maximum aeration rate with our aerator. To do this, we had to determine the relationships between the operating variables. These variables include water flow rates through the tower, air input to the tower, elevation of the tower and oxygen absorption. Water oxygen concentrations at the top of the tower were always at or near saturation. This indicates the most efficient level of air input was below our range of input, and therefore I will not include oxygen absorption in the following analysis.

We may consider water flow rate our dependent variable, with air input and tower elevation our independent variables. Tower elevation is the more important independent variable over the range of air input values tested, since its influence on water flow rate is much greater (Figure 24). At low air input almost twice as much water flows through the tower when the inner tube is 0.5 m below the lake's surface level, compared to when it is 0.5 m above. This difference diminishes at the higher air input levels, but the lower tower elevation is still the most effective level. On the average, water flow rates are 1.3 times as great as high air input, compared to low air input. A more thorough analysis of the

Figure 24. Water flow rates through the hypolimnion aeration tower as a function of air input and tower level. The (O) level is when the top of the inner tube is level with the lake's surface. (+) level is with the inner tube's top 0.5 m above the lake's surface, and the (-) level is with its top 0.5 m below the lake's surface. See text for discussion of true flow rates.

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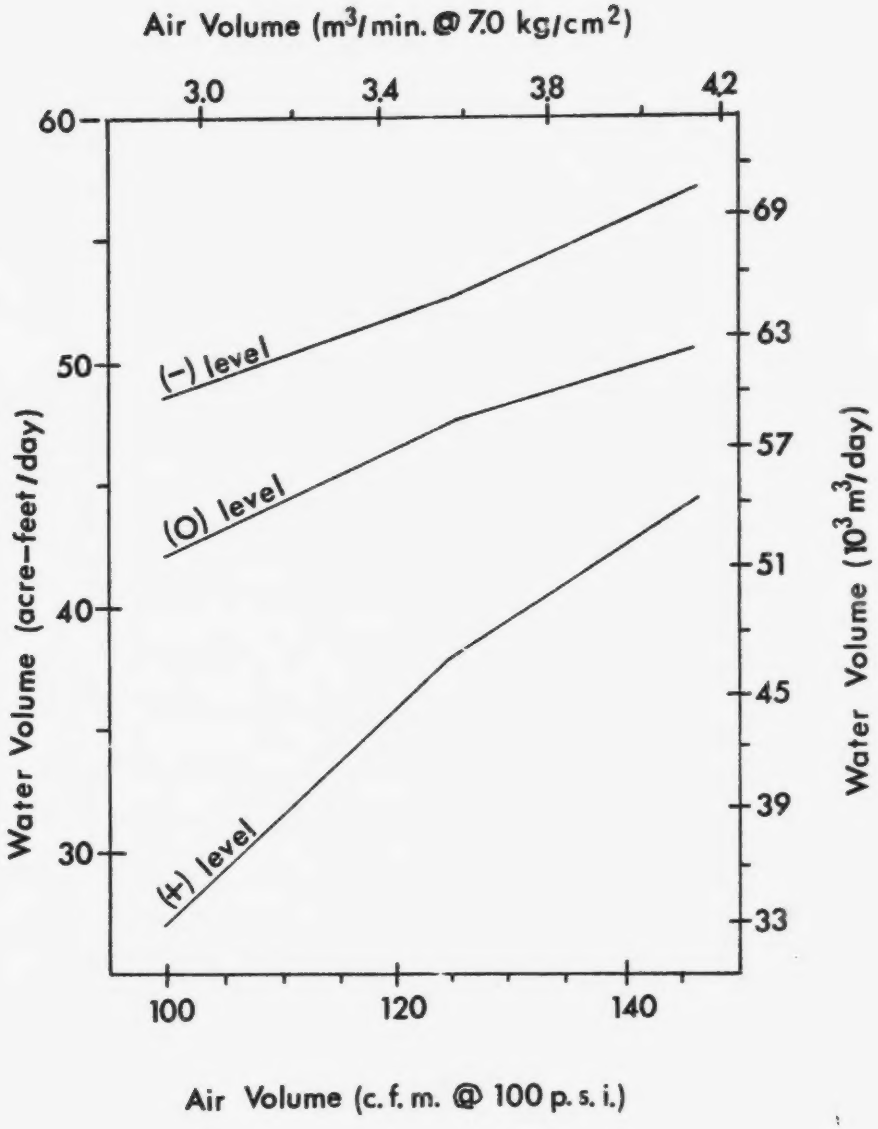

Air Volume (m³/min. @ 7.0 kg/cm²)
3.0
3.4
3.8
4.2
60
50
40
30
Water Volume (acre-feet/day)
69
63
57
51
45
39
33
Water Volume (10³ m³/day)
(−) level
(O) level
(+) level
100
120
140
Air Volume (c.f.m. @ 100 p.s.i.)

flow characteristics should include a wider range of air input. We were limited in this analysis to only three levels because we could not accurately determine air input other than at the standard compressor speeds.

The efficiency of air input can be measured by water volume/day divided by air volume/min. Comparing air input efficiencies, we see that the efficiency decreases for the (0) and (-) tower levels as the air input is increased. The efficiency is relatively unchanged for (+) tower level, however. This indicates that more water is moved per unit of air input at the lower air input levels. The most efficient level of air input is undoubtedly below our range of values. However, as air input is decreased, the water oxygen concentration may decrease below saturation. If this occurs, then the measure of efficiency must also account for oxygen concentration as well as water flow rate.

Our measured water flow rates may be excessive. The current meter does not measure the direction of flow, only the rate. It measured horizontal as well as vertical flow. The horizontal component may be very important, since the flow pattern was eccentric. Because the tower tilted, air tended to rise along the higher side of the tube. In contrast, the return water flow was much greater on the lower side than the upper at all three tower elevations. As much as a seven-fold difference in return flow rates was observed between the upper and lower side. This disparity is undoubtedly due to water flow around the tower as well as through it. The horizontal flow was measured as vertical flow and resulted in excessive flow-through estimates. The measured flow rates are probably relative to each other, however, and therefore can be used to compare tower elevation and air input rate efficiencies.

RESULTS

Physical-Chemical Parameters

Temperature and Oxygen. Hemlock Lake stratified normally during 1969. By early June the metalimnion extended from 3 to 8 meters (Figure 25), and the monimolimnion began at 14 meters. Temperatures during early June 1969 ranged from 18°C at the surface to 4.5°C at the bottom. During this same period, oxygen values averaged 8.0 mg/l at the surface and 0.0 mg/l at the bottom (Figure 26). Metalimnion oxygen maxima of as much as 15.0 mg/l were often observed throughout the summer. These oxygen maxima were caused by high photosynthetic efficiencies and reduced mixing and diffusion rates. Chlorophyll concentrations were not very great in either the epilimnion or metalimnion (Figure 27), indicating the oxygen maxima were not caused by algal concentrations. As the season progressed, the metalimnion depth increased slightly. By late August it extended from 4 to 10 meters. The 7°C through 15°C isotherms have a nearly parallel decline throughout the summer. Maxima surface temperatures of over 25°C were observed during mid-July 1969 and again during mid-August. Minimum temperatures were nearly constant at 4.5°C. The oxygen depletion depth was nearly constant at 10.5 meters during the entire summer 1969 (Figure 28).

Figure 25. Hemlock Lake's isotherms during the summer 1969, before aeration began. Isotherms are in °C.

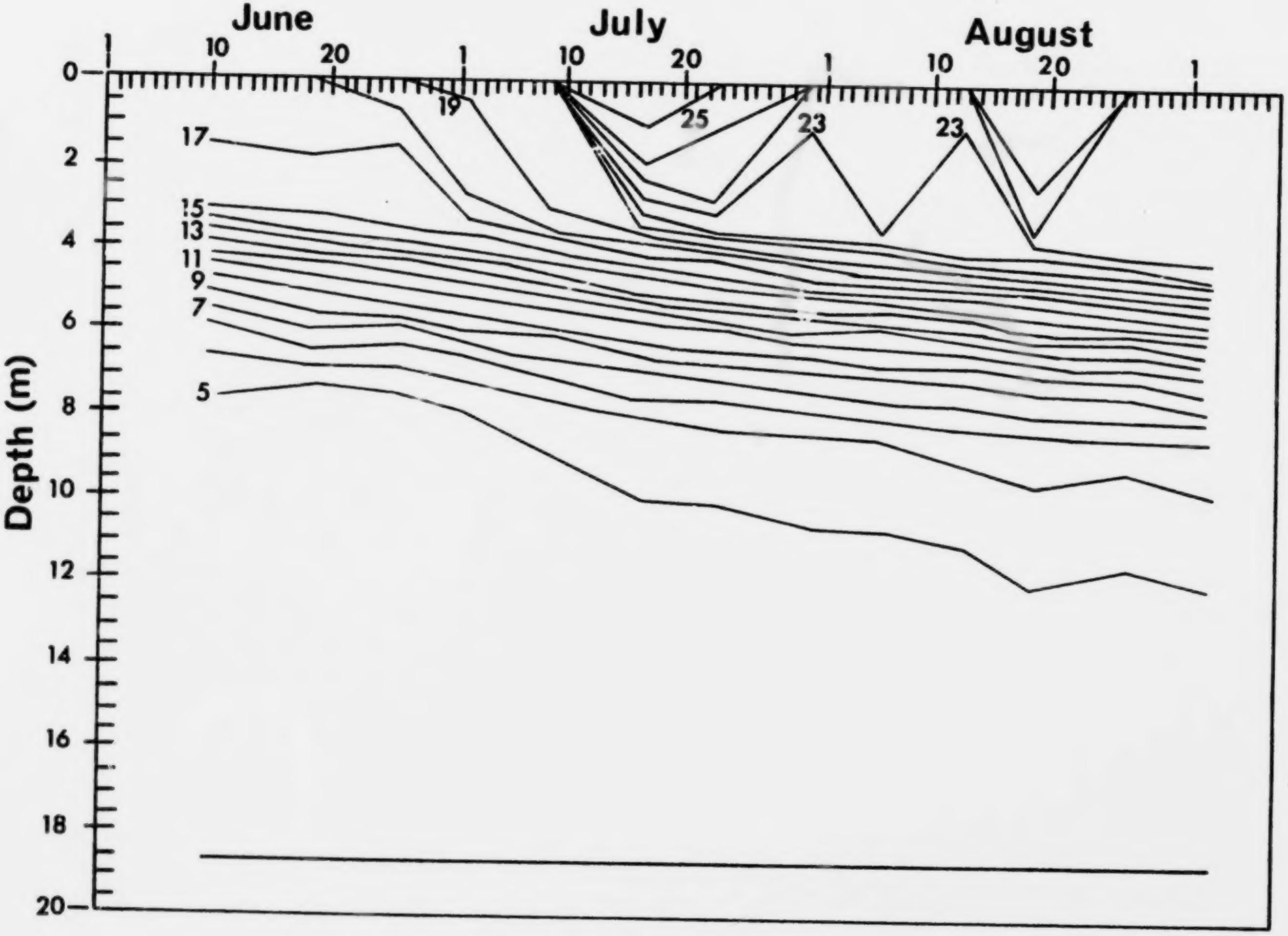

June
July
August
1
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
17
15
13
11
9
7
5
19
25
23
23

Figure 26. Hemlock Lake's top, bottom and average oxygen concentrations during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.

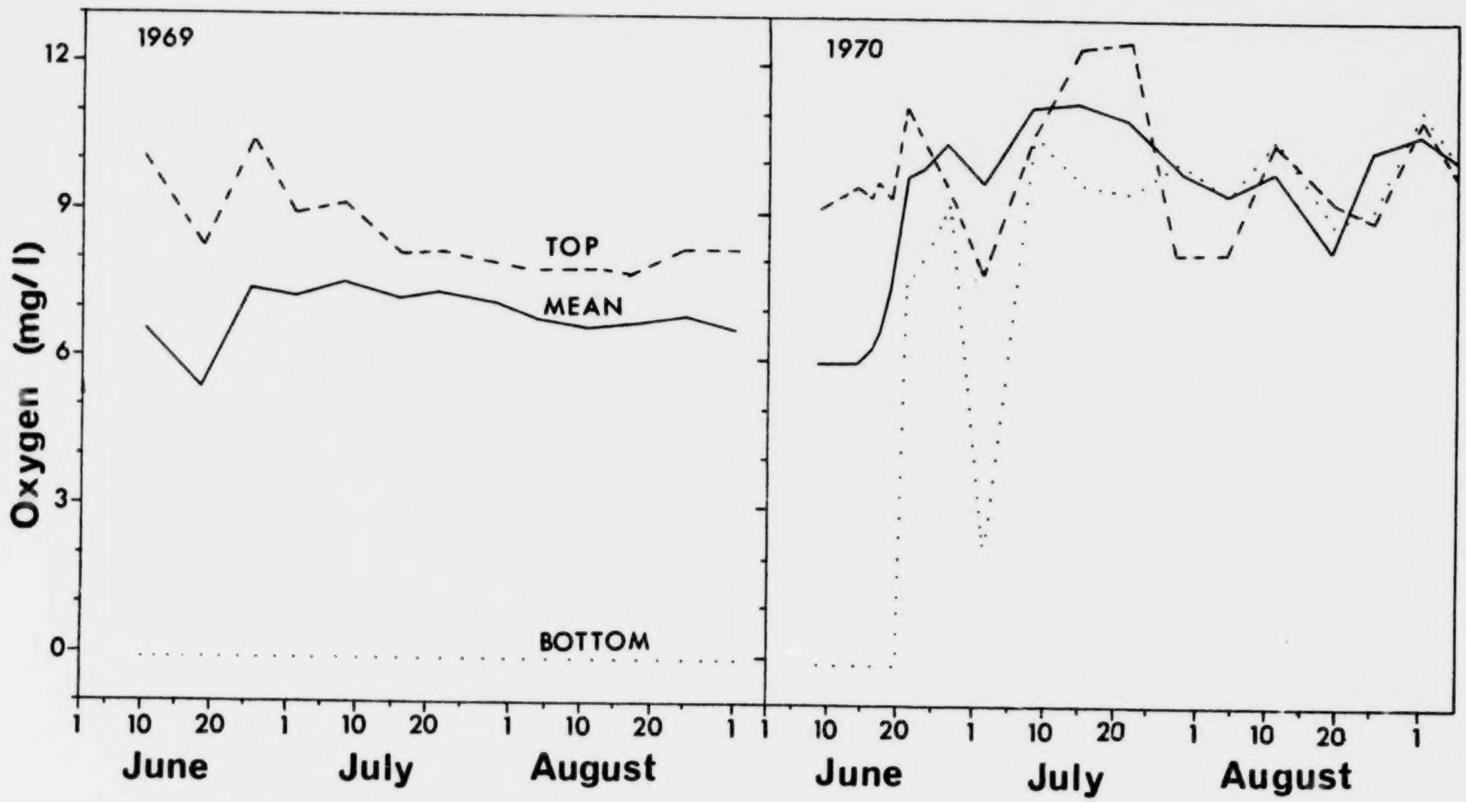

1969
1970
Oxygen (mg/l)
12
9
6
3
0
TOP
MEAN
BOTTOM
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 27. Hemlock Lake's total chlorophyll A, phaophytin A, oxygen and temperature profiles during August 13, 1969. These are representative of values before aeration began.

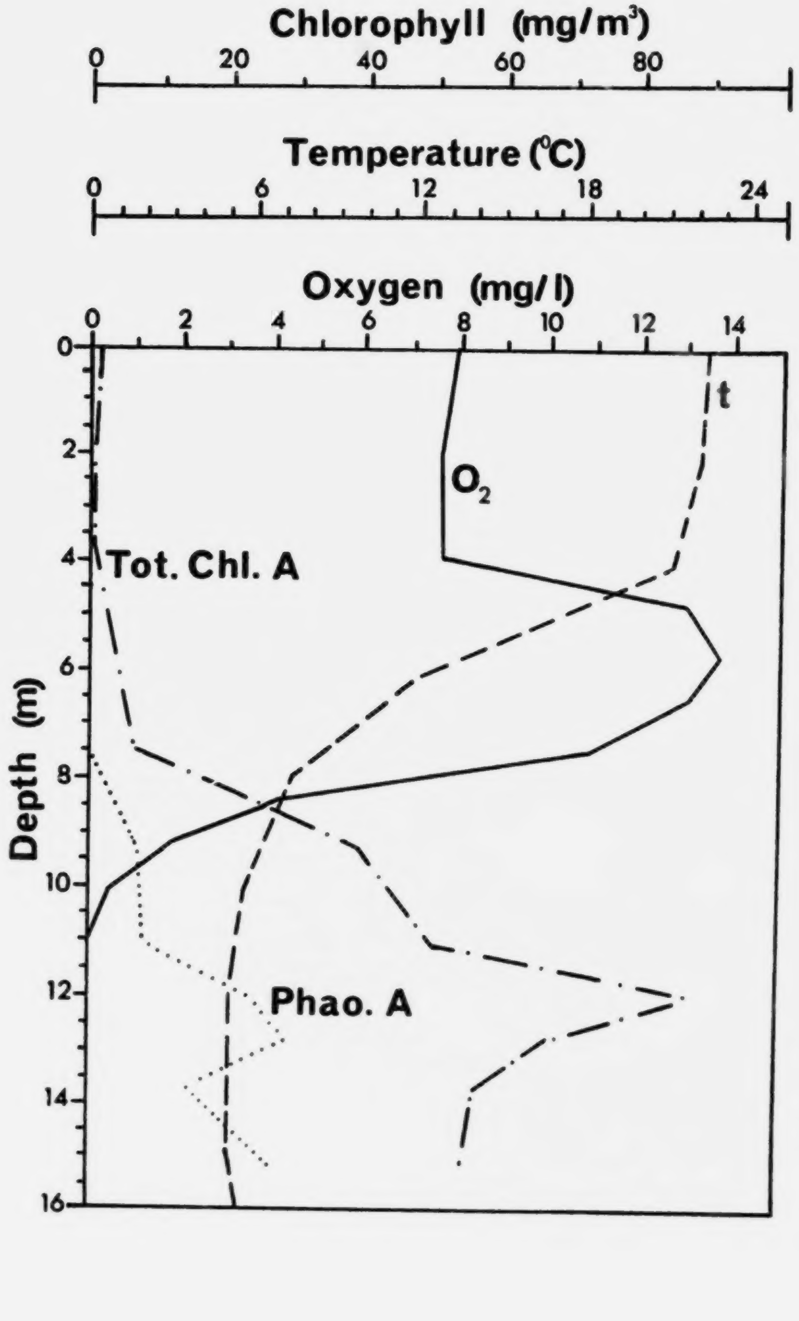
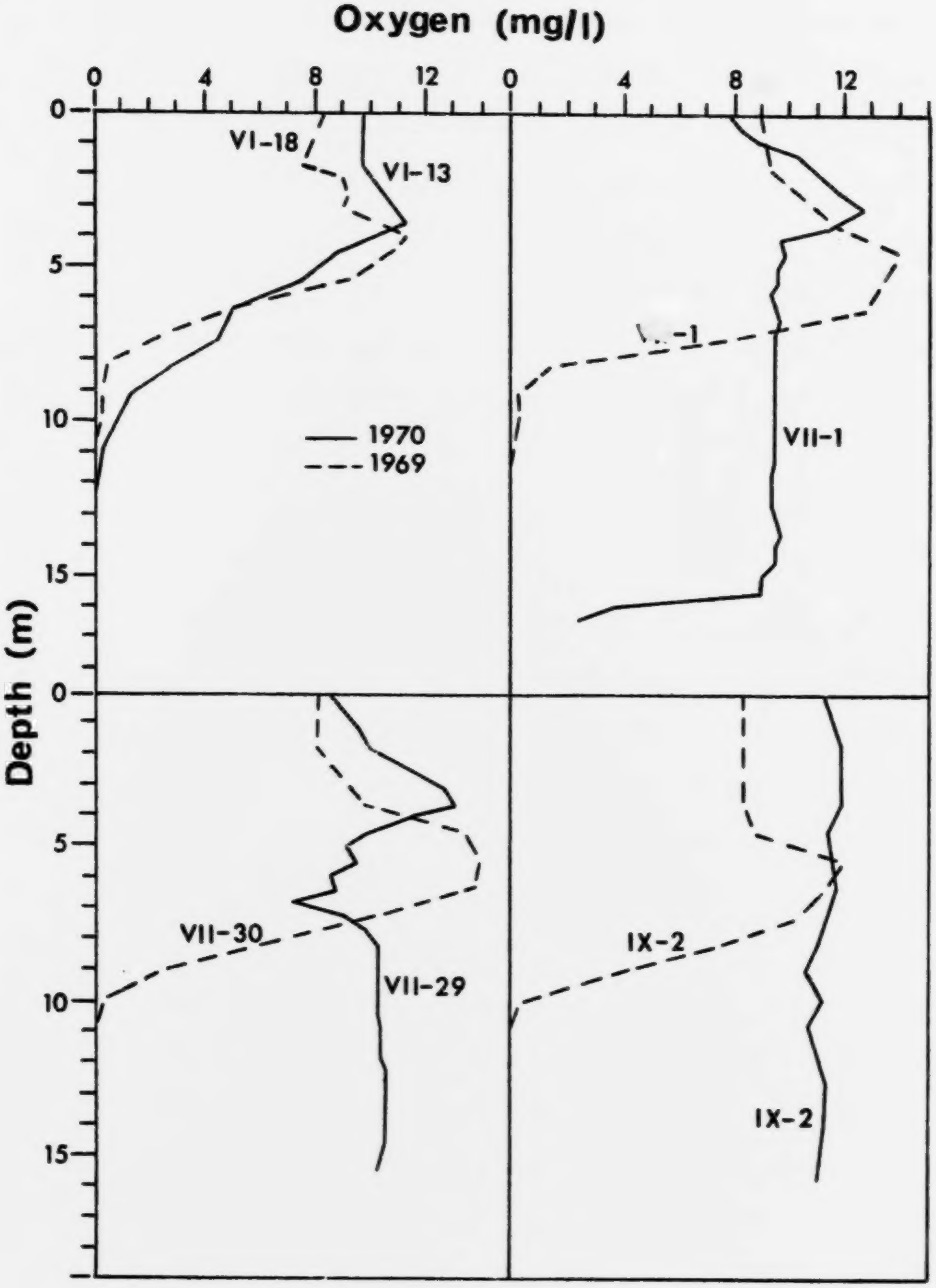

Chlorophyll (mg/m^3)
0
20
40
60
80
Temperature (°C)
0
6
12
18
24
Oxygen (mg/l)
0
2
4
6
8
10
12
14
Depth (m)
0
2
4
6
8
10
12
14
16
t
O$_2$
Tot. Chl. A
Phao. A

Figure 28. Hemlock Lake selected oxygen profiles during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.


Oxygen (mg/l)
0
4
8
12
0
4
8
12
Depth (m)
0
5
10
15
0
5
10
15
VI-18
VI-13
— 1970
--- 1969
VII-1
VII-30
VII-29
IX-2
IX-2

Before aeration began during June 1970, the thermal regime was similar to that of June 1969 (Figure 29). Temperatures ranged from 21°C at the surface to 4.5°C at the bottom (Figure 30). Although the surface temperature was warmer during June 1970, the thermal profile was otherwise similar. Oxygen values before aeration began during 1970 were likewise very similar to the 1969 values. Oxygen depletion began at 12 meters, and a maxima occurred within the metalimnion.

Continuous artificial hypolimnion aeration began June 14, 1970 and caused significant alterations of the physical-chemical regime. A tongue of 1.0 to 4.0 mg/l oxygen extended from the aeration into the hypolimnion after one day of continuous aeration (Figure 31). After nine days of aeration, much of the hypolimnion had over 8 mg/l oxygen (Figure 32). Shortly thereafter the entire hypolimnion had more than 10 mg/l oxygen.

Bottom oxygen concentrations at maximum depth increased from 0.0 mg/l to 9 mg/l during the first week of aeration, and remained above 10 mg/l most of the summer (Figures 26 and 28). Oxygen maxima still occurred within the metalimnion, but they were not as distinct as during pre-aeration periods. Average oxygen concentrations were always greater during aeration, and surface values were generally greater. Average oxygen concentrations during mid-July 1970 were 12 mg/l compared to 8.5 mg/l during mid-July 1969 (Figure 26).

Figure 29. Hemlock Lake's isotherms during the summer 1970. Continuous aeration occurred between June 14th and September 7th. Isotherms are in °C.

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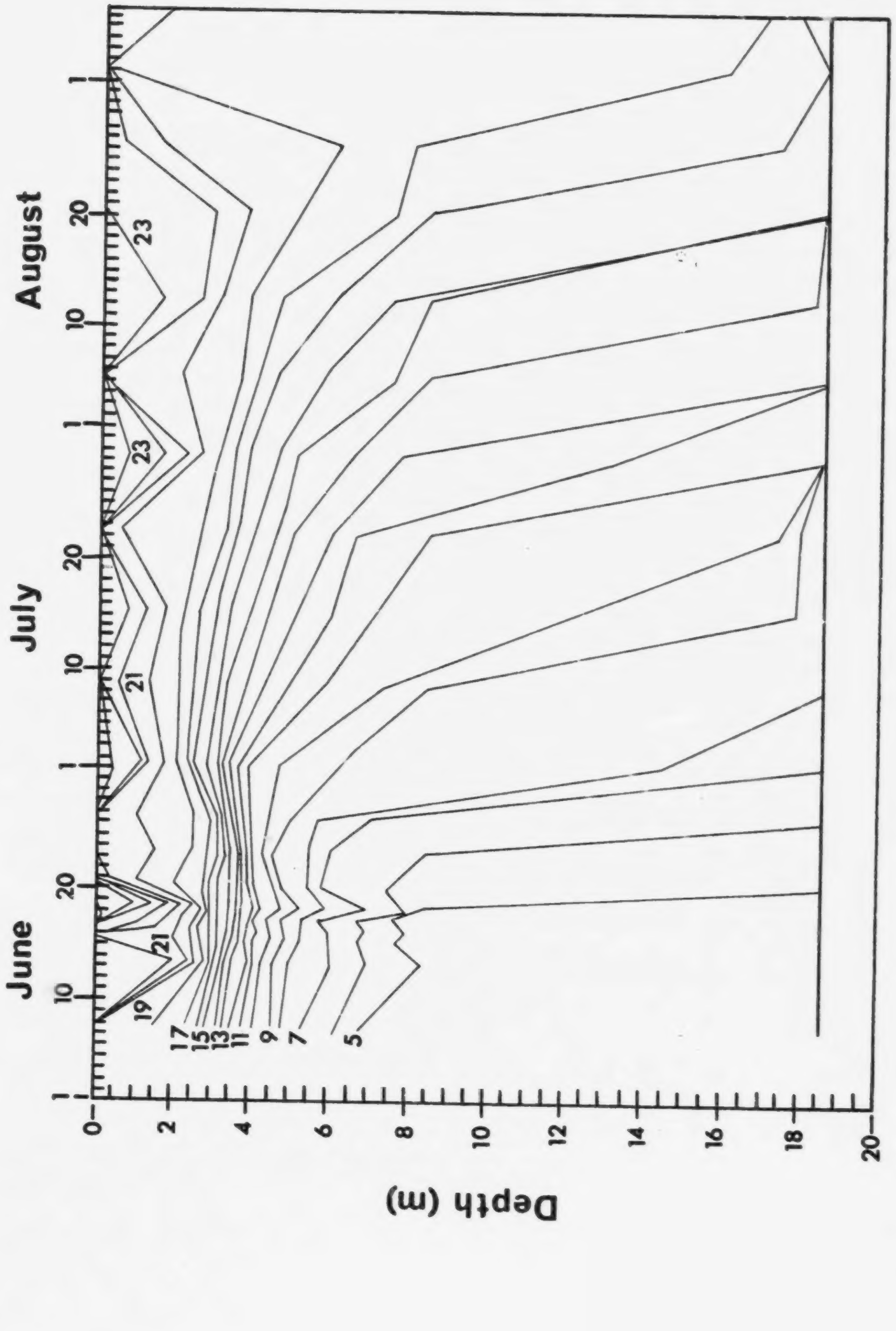

Depth (m)
0
2
4
6
8
10
12
14
16
18
20
June
July
August
1
10
20
1
10
20
1
10
20
1
5
7
9
11
13
15
17
19
21
21
23
23

Figure 30. Hemlock Lake selected temperature profiles during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.

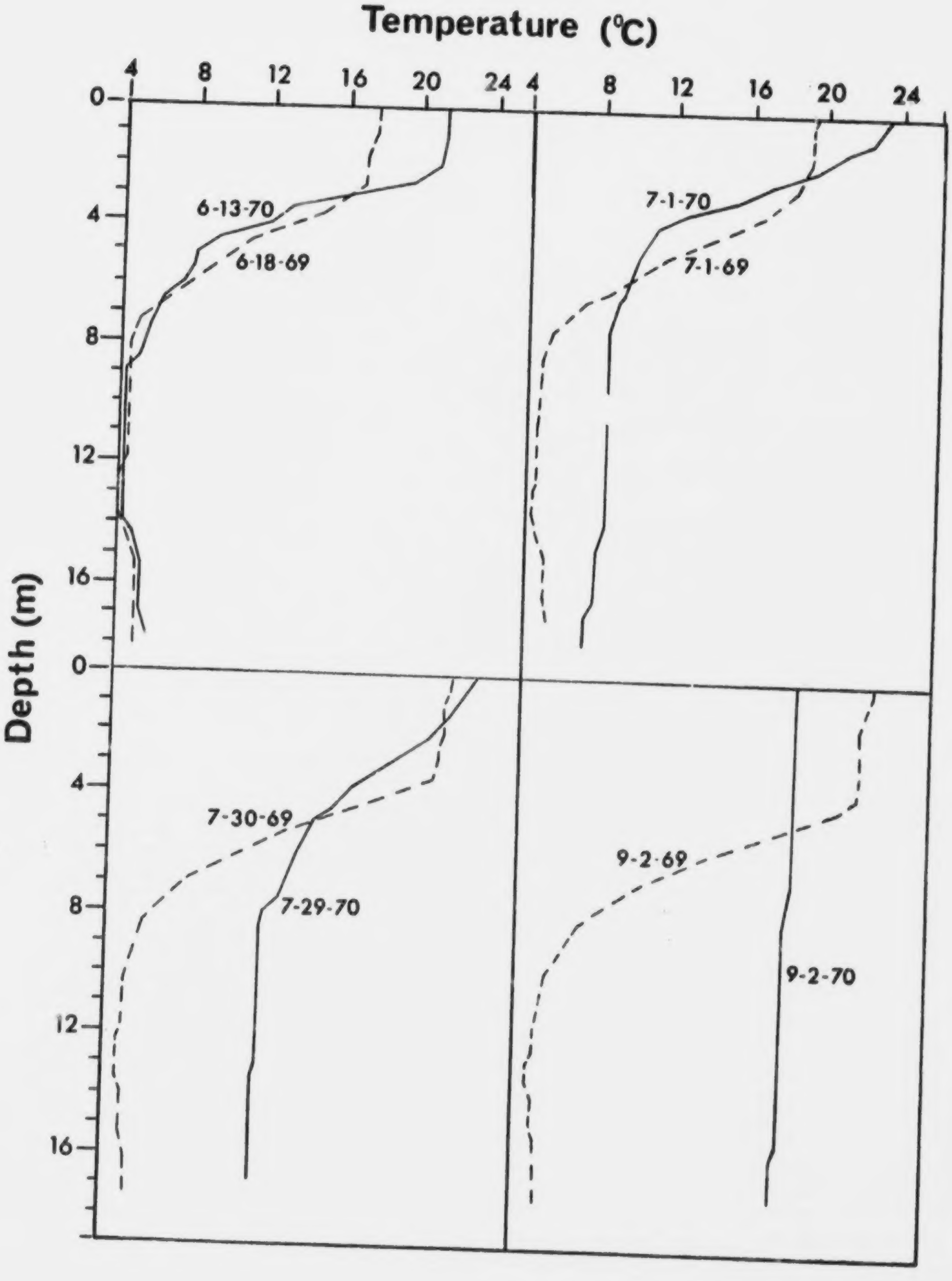

Temperature (°C)
4
8
12
16
20
24
4
8
12
16
20
24
Depth (m)
0
4
8
12
16
0
4
8
12
16
6-13-70
6-18-69
7-1-70
7-1-69
7-30-69
7-29-70
9-2-69
9-2-70

Figure 31. Hemlock Lake hypolimnetic oxygen isopleths (mg/l) along the air line transect one day before aeration began and after one day of hypolimnion aeration.

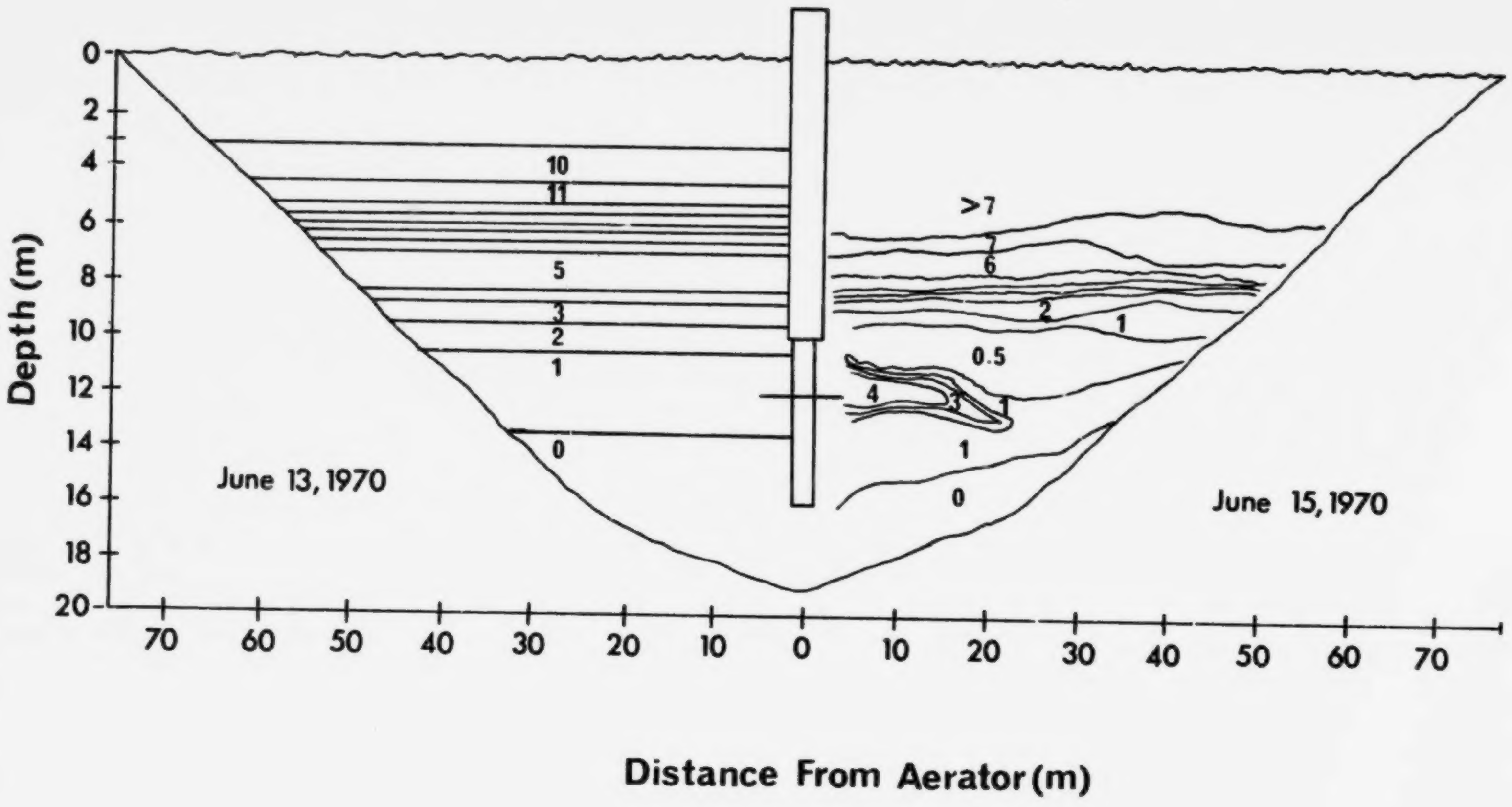
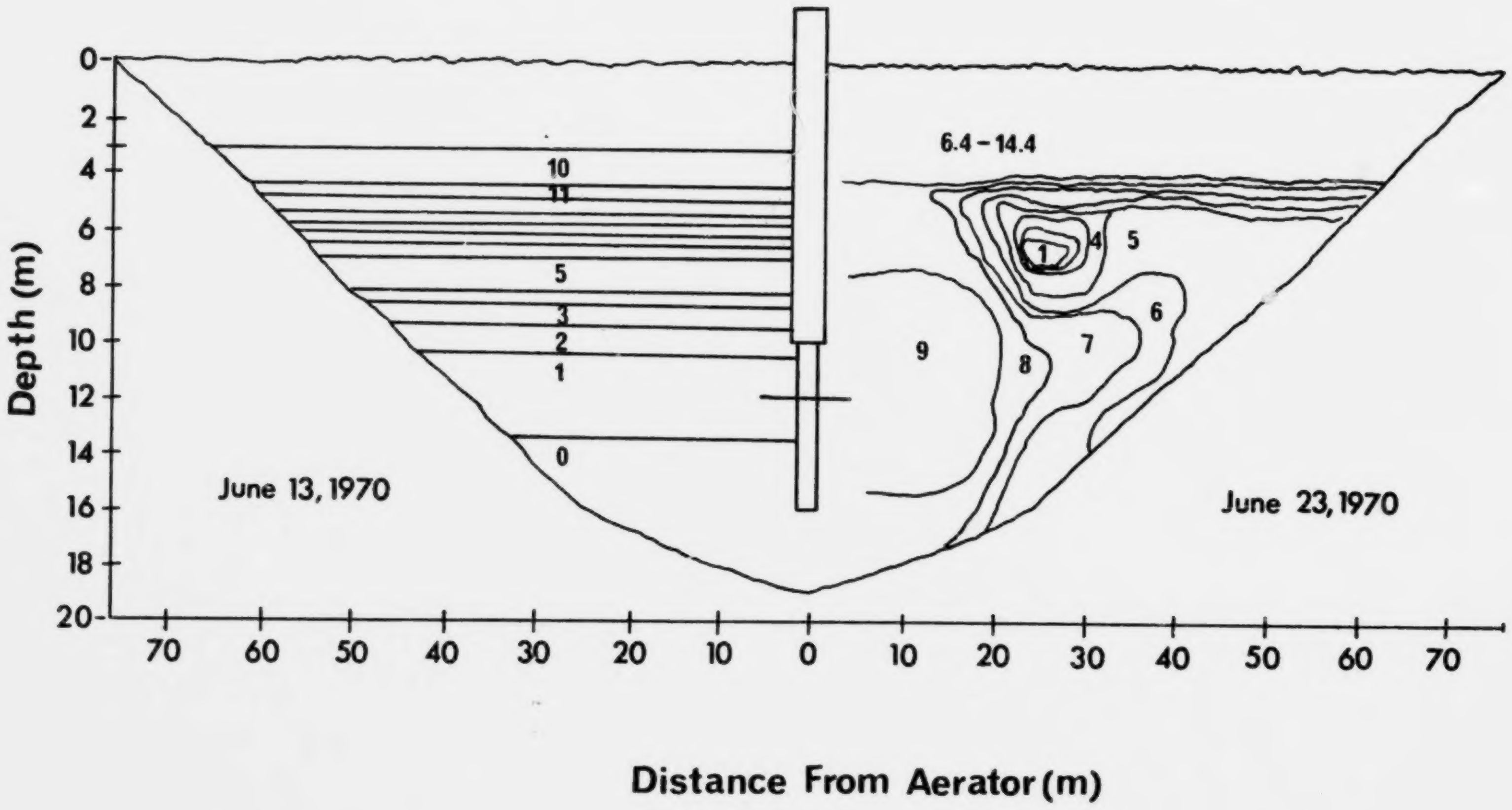

Depth (m)
0
2
4
6
8
10
12
14
16
18
20
10
11
5
3
2
1
0
>7
7
6
2
1
0.5
4
3
1
1
0
June 13, 1970
June 15, 1970
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
Distance From Aerator (m)

Figure 32. Hemlock Lake hypolimnetic oxygen isopleths (mg/l) along the air line transect one day before aeration began, and after nine days of continuous hypolimnion aeration.


Depth (m)
0
2
4
6
8
10
12
14
16
18
20
Distance From Aerator (m)
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
June 13, 1970
June 23, 1970
10
11
5
3
2
1
0
6.4 - 14.4
1
4
5
6
7
8
9

Another conspicuous alteration of Hemlock's physical-chemical regime is the gradual warming of the hypolimnetic waters. Their temperature increased more than 2°C/week (Figures 29 and 33). This increase is marked by the gradual and continued extinction of 18°C or less isotherms, "into the bottom of the lake." The minimum temperature increased greatly to over 17°C during September 1970, compared to 4.5°C the previous September. The average temperature increased to a maximum of 19.5°C during August 1970, compared to 17.5°C summer maximum during August 1969. Surface temperatures were slightly cooler during July 1970, and several degrees cooler during late August 1970 compared with 1969. The hypolimnetic warming is attributed to heat conductions throughout the tower, whereas the surface cooling is attributed to mixing of hypolimnetic waters with surface waters. This led to a gradual destratification of Hemlock Lake in disaccordance with my experimental design. Although the lake did destratify almost completely by September 1970, I did maintain a distinct thermal gradient during most of the summer.

Thermal Stability. Thermal stability increased from 7×10^8 kg-m during June 1969 to 18×10^8 kg-m during July and August. These two peaks correspond to surface temperature maxima (Figure 34). The increased stability reflects the general surface warming trend, increased epilimnetic volume and thermal gradient maintenance during 1969. Thermal stability followed a much different pattern during 1970. It increased

Figure 33. Hemlock Lake maximum, minimum and average temperatures (^{o}C) during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.

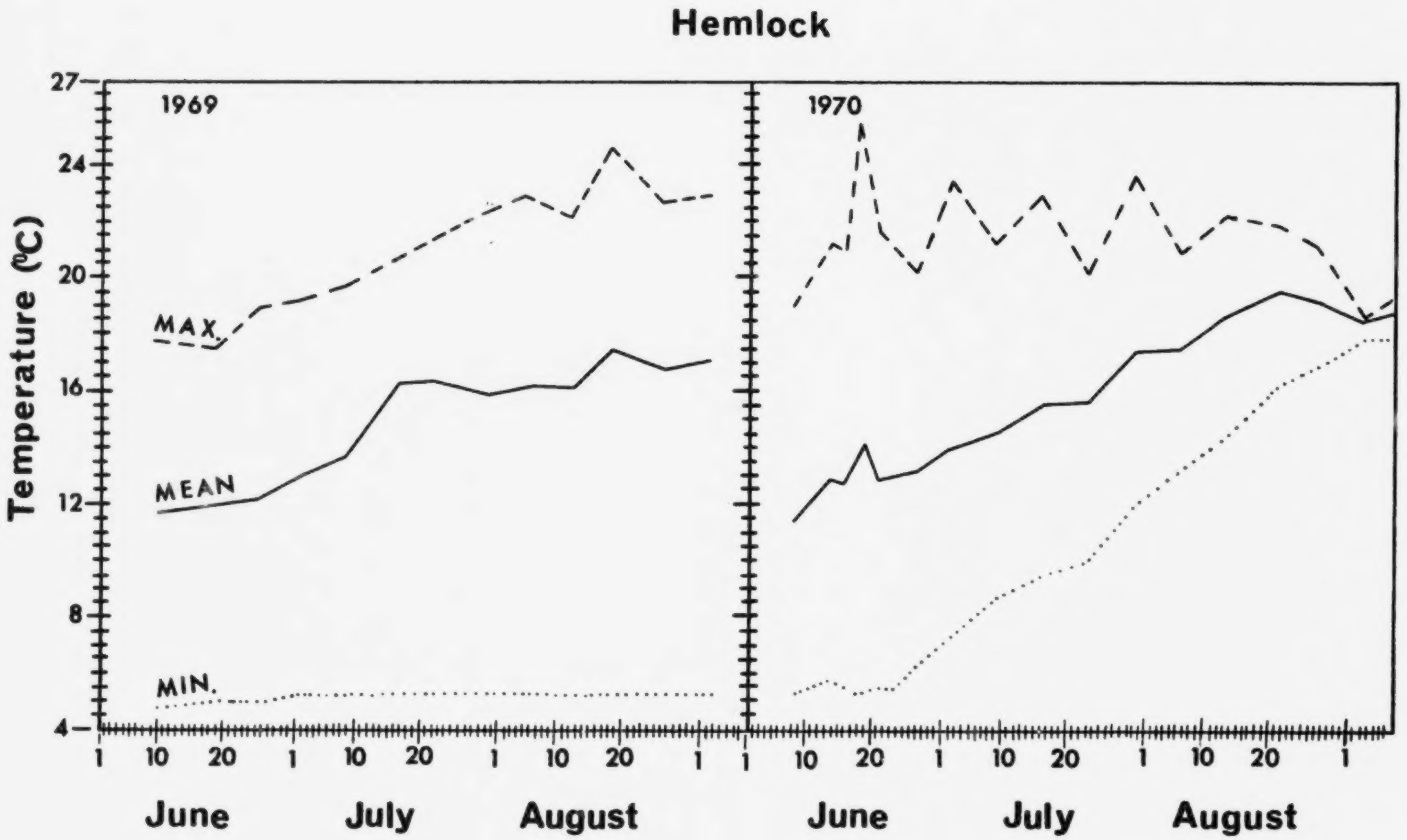
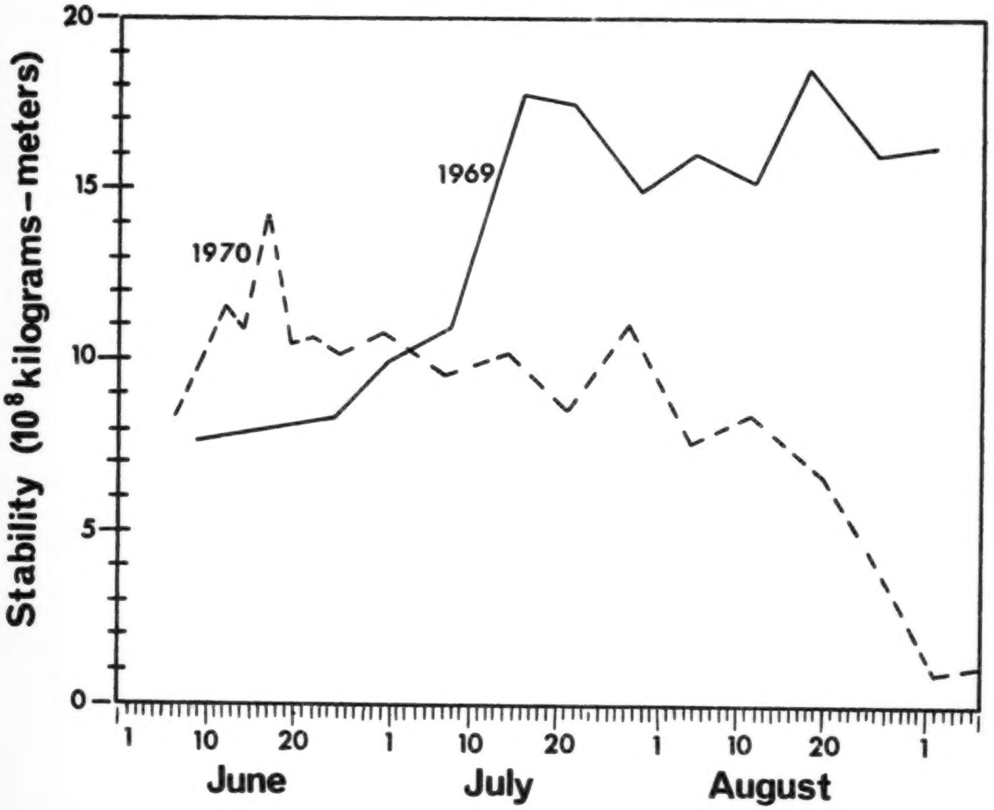

Hemlock
Temperature (ºC)
27
24
20
16
12
8
4
1969
MAX.
MEAN
MIN.
1970
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 34. Hemlock Lake stability values during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.


Stability (10^8 kilograms-meters)
20
15
10
5
0
1970
1969
1
10
20
1
10
20
1
10
20
1
June
July
August

from 8×10^8 kg-m during early June 1970 to a 14.5×10^8 kg-m maximum during mid-June. Thereafter it decreased gradually to almost zero by September 1970. This gradual decrease in stability reflects the gradual destratification of the lake.

pH, Alkalinity, and Conductivity. During 1969, pH values were consistently low within the monimolimnion, but about 8.0 near the surface (Figure 35). The low monimolimnetic values are attributed to high carbon dioxide concentrations associated with decomposition of seston and sediments. After aeration began during 1970, the bottom pH values increased and eventually equaled the surface values. Surface values were greater during early 1970 than during 1969, but gradually declined. The high surface pH values are attributed to photosynthesis, whereas the increases in bottom pH values are attributed to carbon dioxide elimination. Carbon dioxide was removed from the bottom water as it passed through the aerator tower.

Surface and bottom total alkalinity values differed greatly during 1969. Surface values were relatively constant at 120 mg/l, but bottom values were about 500 mg/l (Figure 36). Aeration caused a marked decrease in bottom alkalinity, but a gradual increase in surface alkalinity. The average alkalinity was relatively constant and about the same as during 1969.

Conductivity followed the same general pattern as total alkalinity (Figure 37). Bottom conductivity during 1969

Figure 35. Hemlock Lake's bottom, top and average pH values during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.

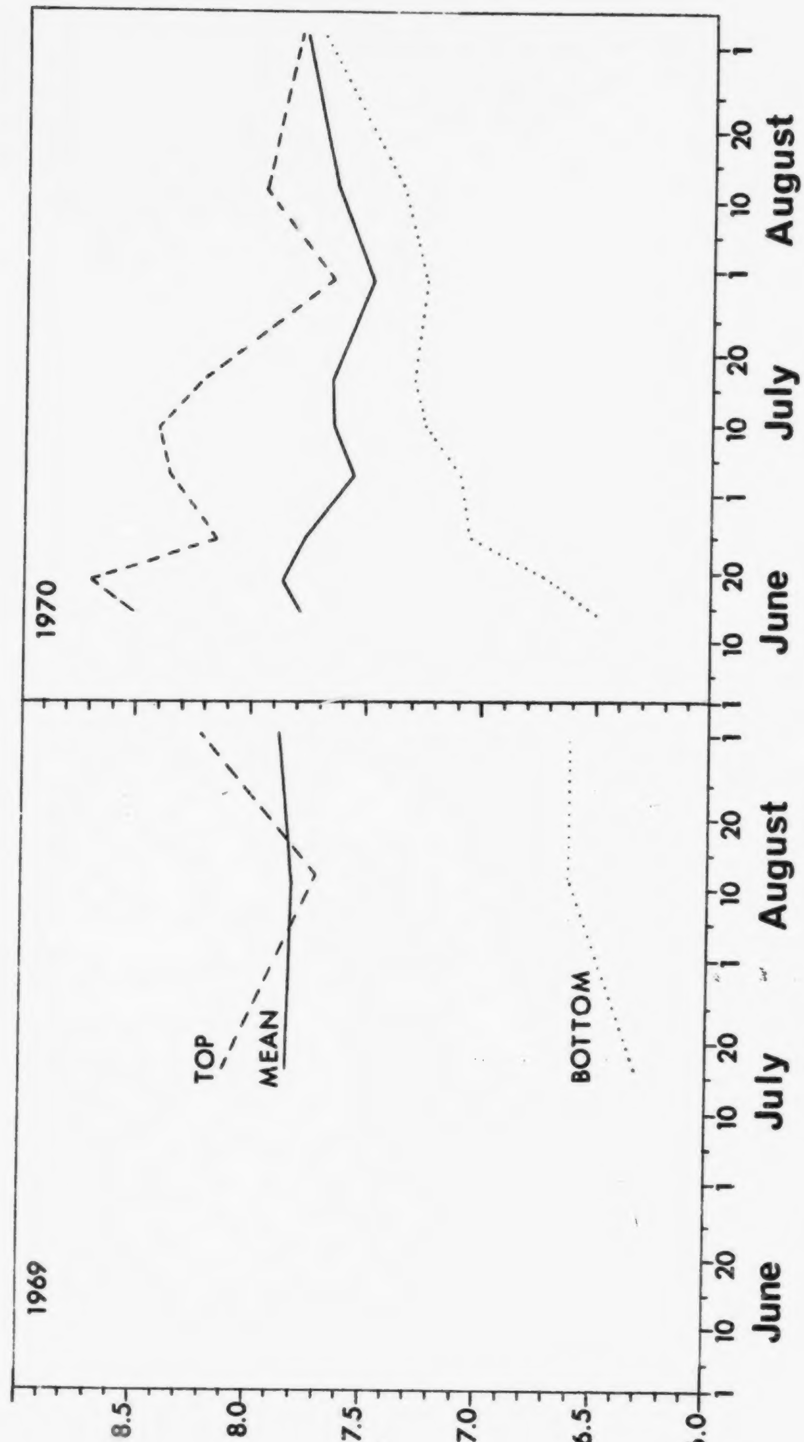

pH
8.5
8.0
7.5
7.0
6.5
6.0
1969
1970
TOP
MEAN
BOTTOM
June
July
August
1
10
20

Figure 36. Hemlock Lake's bottom, top and average alkalinity values during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.

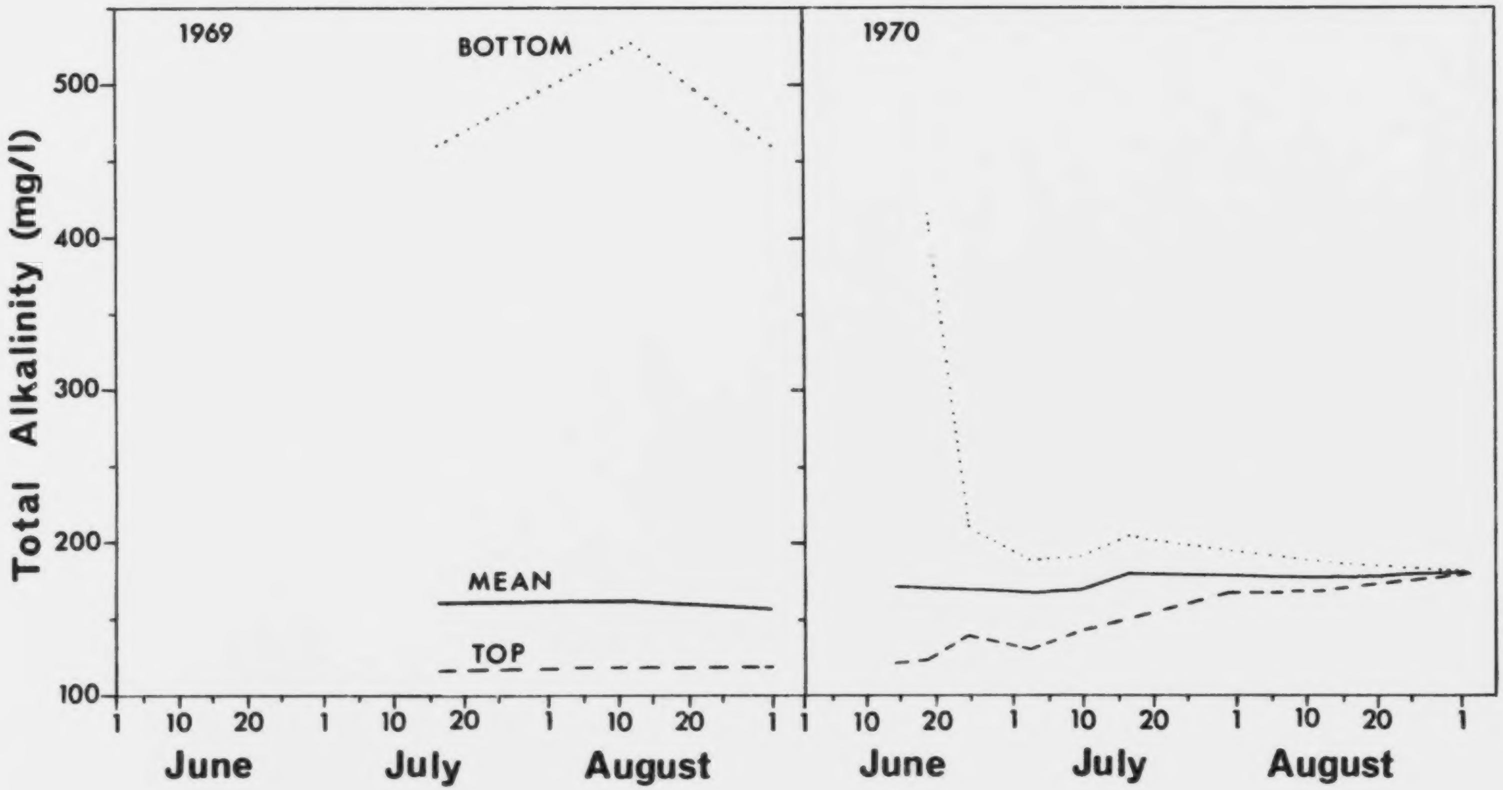
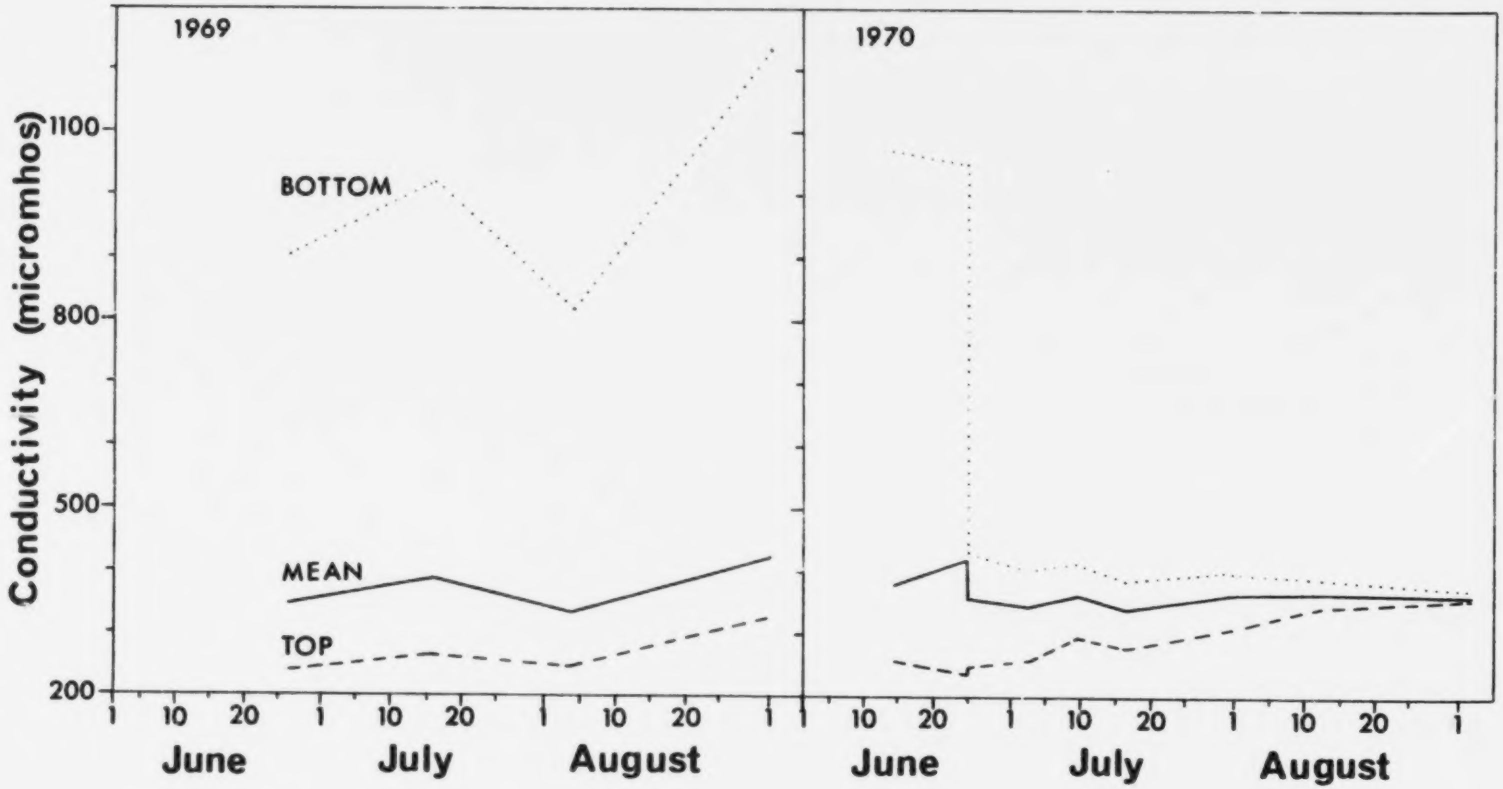

1969
BOTTOM
MEAN
TOP
1970
Total Alkalinity (mg/l)
500
400
300
200
100
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 37. Hemlock Lake's bottom, top and average conductivity values during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.


1969
1970
Conductivity (micromhos)
1100
800
500
200
BOTTOM
MEAN
TOP
1
10
20
June
July
August

averaged 950 micromhos compared to 250 at the surface. Following aeration during 1970, the bottom conductivity decreased rapidly to 400 micromhos and then gradually converged with surface conductivity. When the lake destratified, the surface and bottom conductivity were essentially equal.

Phosphorus. Total phosphorus concentrations during July 1969 were ten times as great in the monimolimnion as in the holomixion (Table 3). They ranged from 0.020 mg/l at the surface to 0.280 mg/l at the bottom. Total dissolved phosphorus did not follow this same pattern. It was more variable, but about twice as great below the metalimnion. Surface to 3.7 meter samples averaged .011 mg/l whereas those below 10 meters averaged .021 mg/l. Phosphorus determinations were not made during 1970, but changes in their concentrations can be inferred. Oxygen depletion leads to low redox potentials in the mud and a net movement of phosphorus from the mud to the water (Mortimer, 1941, 1942). This situation was evident before aeration began. After aeration began the redox potential increased rapidly as the oxygen increased. This caused a re-absorption of phosphorus by the aerated mud (Fitzgerald, 1970) and precipitation of phosphorus. The net concentration of phosphorus should thus decrease. Subsequent accelerated biodegradation of the sediments may have caused a regeneration of phosphorus. The net result of the processes is speculative.

Table 3. Hemlock Lake total phosphorus and total dissolved phosphorus collected July 22, 1969. Two water samples were collected from each depth.

Depth	Total Phosphorus (mg/l)			Total Dissolved Phosphorus (mg/l)		
	x_1	x_2	Mean	x_1	x_2	Mean
0.0	0.020	0.020	0.020	0.010	0.015	0.012
1.9	0.015	0.020	0.018	0.008	0.008	0.008
3.7	0.025	0.015	0.020	0.020	0.008	0.014
5.6	0.008	0.010	0.009	0.002	0.005	0.004
7.4	0.008	0.020	0.014	0.005	0.020	0.012
9.2	0.040	0.040	0.040	0.008	0.040	0.024
11.0	0.025	0.030	0.028	0.025	0.015	0.020
12.8	0.020	0.030	0.025	0.020	0.025	0.023
14.6	0.300	0.250	0.280	0.020	0.020	0.020

Ca, Na, K, Mg, DOM and POM. These constituents were measured only during the summer 1970. The average concentrations of sodium and magnesium were relatively constant during the summer (Table A-11). Particulate organic matter was especially variable. Calcium, potassium and dissolved organic matter had intermediate variability.

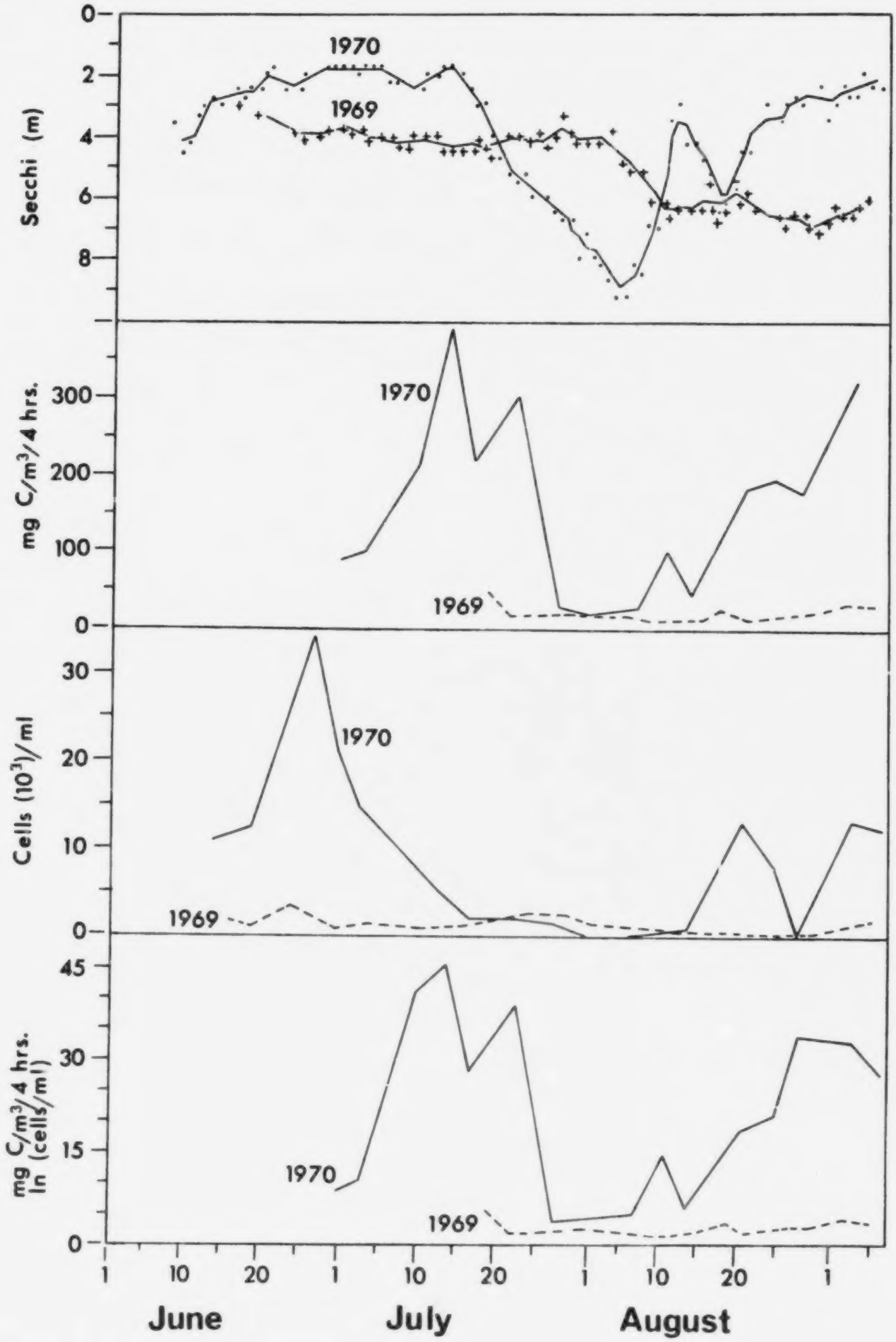
Primary Production

Phytoplankton. Relative to 1970, Hemlock's phytoplankton parameters were relatively stable during 1969. Secchi disc measurements during 1969 ranged between 2.5 and 6.5 m (Figure 38). Surface phytoplankton densities were always less than 4,000 cells/ml, and surface ^{14}C production estimates were always less than 50 mg $C/m^3/4$ hrs.

A small, unidentified bacterium was very abundant within the monimolimnion during the summer 1969. Brian Moss found that its density often exceeded 300,000 cells/ml. Water from this region had a distinct green tinge, although the bacterium was pink when preserved. Gallionella was occasionally collected from 15 m while not found at 0 m or 5 m. Other phytoplankters were infrequently collected at 15 m, but were presumably produced at shallower depths.

After aeration began during June 1970, dramatic changes occurred. Secchi disc measurements decreased to 1.7 m after a week of aeration. Concurrently, phytoplankton densities increased to over 30,000 cells/ml. Primary production also

Figure 38. Hemlock Lake secchi disc transparencies, surface primary production potentials, surface phytoplankton densities and surface production efficiencies during the summers 1969 and 1970. Continuous aeration occurred between June 14 and September 7, 1970.


Secchi (m)
0
2
4
6
8
1970
1969
mg C/m³/4 hrs.
300
200
100
0
1970
1969
Cells (10³)/ml
30
20
10
0
1970
1969
mg C/m³/4 hrs.
ln (cells/ml)
45
30
15
0
1970
1969
1
10
20
1
10
20
1
10
20
1
June
July
August

increased, but did not reach its maximum of almost 400 mgC/m^3/4 hrs. until mid-July, at which time phytoplankton densities had declined. Following the tremendous increase in phytoplankton production, standing crops declined to an all time low by the first week of August. This is exemplified by the Secchi disc measurement of over 9 meters. This is the deepest Secchi measurement ever recorded for Hemlock Lake. Surface phytoplankton standing crop and ^{14}C production approached zero during the first week of August.

Following this phytoplankton decline, there was a gradual increase that continued throughout August. Secchi disc measurements declined to about 2 meters and ^{14}C estimates increased to over 300 mgC/m^3/4 hrs. by September. Phytoplankton densities also increased to about 10,000 cells/ml, which is about one-third their June maxima.

The bacterium that was so abundant in the monimolimnion during 1969, disappeared soon after aeration began during June 1970. Several phytoplankton species were found in the hypolimnion during the summer 1970, but these were typically more abundant at shallower depths and were probably produced at shallower depths. Densities near the bottom, at 16.5 m followed the same seasonal pattern as found at the surface. Densities were greater than 3,000/ml on June 26th, July 2nd and July 9th, but declined to only 1/ml on July 31st. Densities gradually increased thereafter to 1,700/ml by September.

Associated with changes in the plankton, an unusual event occurred. Beginning about August 1, 1970, voluminous quantities of foam were generated in the aerator. This foam was tan-colored and had a musty odor. Algal cells and Daphnia ephypia were mixed with it. It was sticky, but easily dissolved in water. When dried, it was a dark green or black color, presumably due to entrapped chlorophyll. Large quantities were generated during the night and spilled over the top of the aerator (Figure 39). Large amounts of foam floated about the lakes' surface early in the morning, but were gone by mid-day. The foam was apparently "melted" by the sunlight and/or increased temperatures. From midday on, it completely filled the tower, above the water level, but did not cascade over the rim. It again resumed overflow starting sometime during the night.

The foaming ceased from about August 15th through August 18th. This coincides with a dip in the surface Secchi and ^{14}C measurements. Foaming started again August 19th and continued until we terminated operations. This second time foaming began coincides with an upturn in ^{14}C production at the surface and secchi decreases.

Periphyton. Average periphyton standing crop during 1969, based on 17-day incubations, ranged between 0.004 and 0.020 gm/day (Figure 40). Minimum values occurred during June and maximum during late July and August. Periphyton accumulations in Hemlock were most abundant between the surface and

Figure 39. Foam spilling over the top of the hypolimnion aerator during August 1970. (Photo by author.)

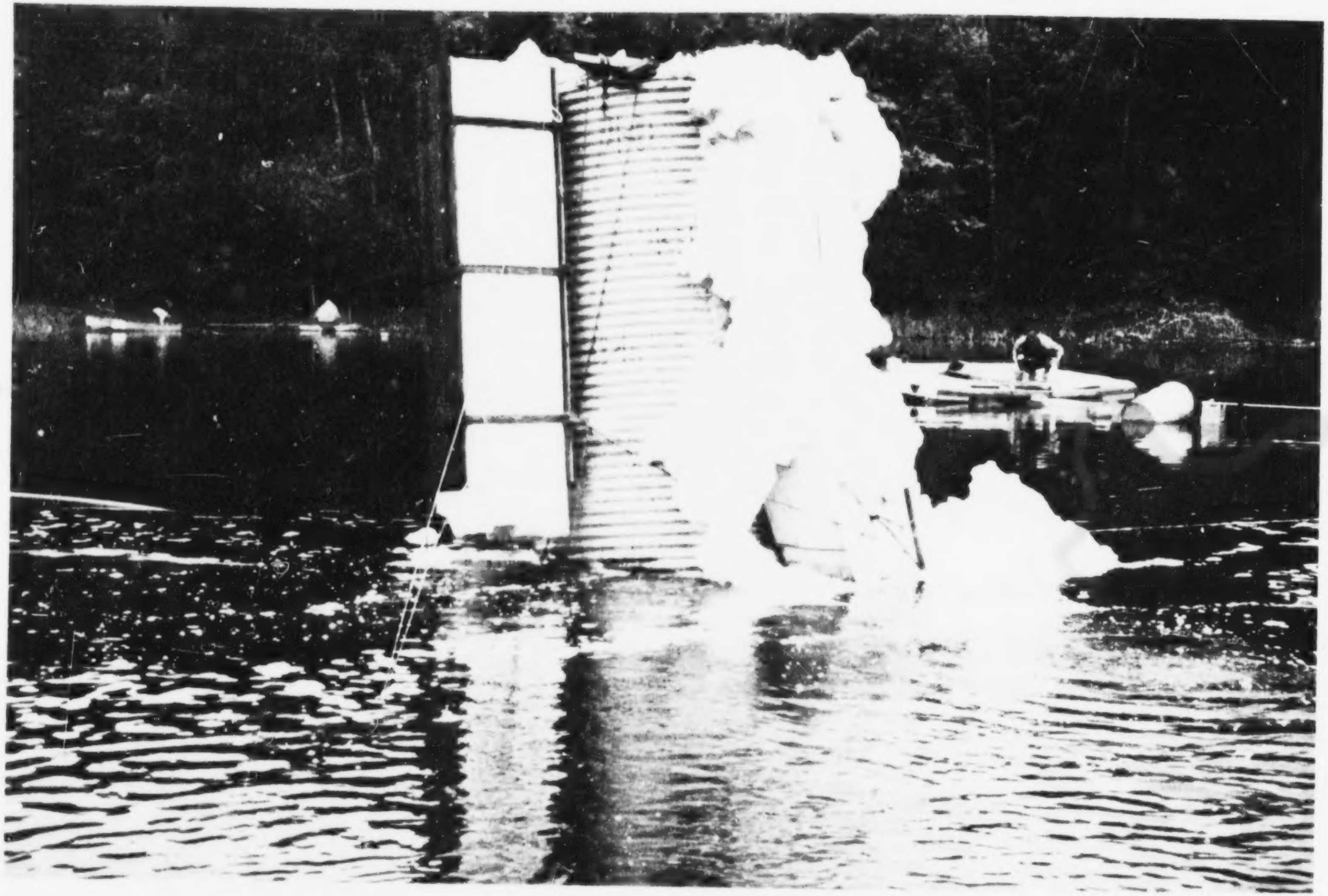
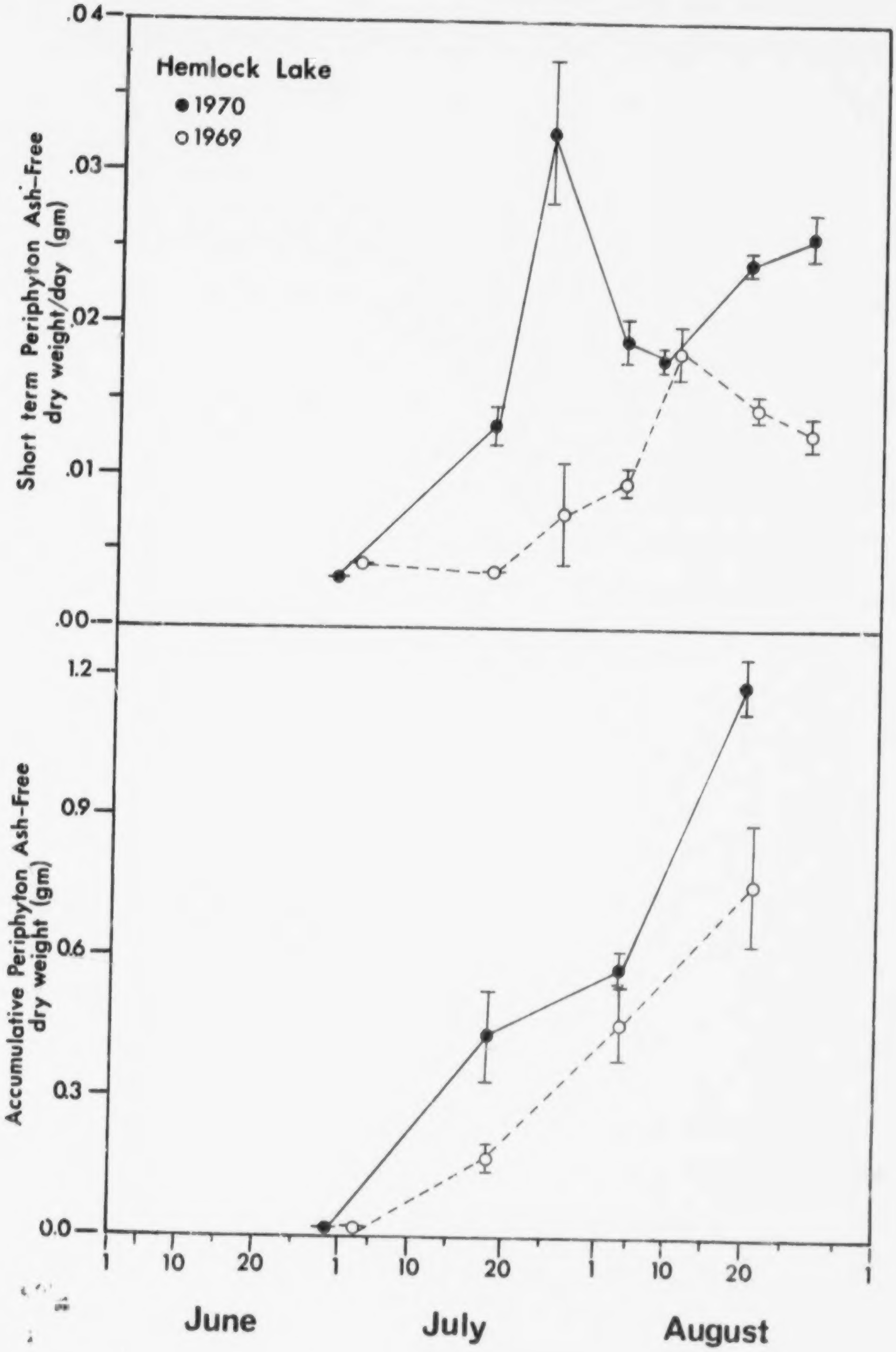


Figure 40. Hemlock Lake periphyton standing crops based on 17-day incubation periods and continuous incubation. The 95% confidence interval is shown about each average value. Continuous aeration occurred between June 14 and September 7, 1970.


Hemlock Lake
● 1970
○ 1969
Short term Periphyton Ash-Free dry weight/day (gm)
.04
.03
.02
.01
.00
Accumulative Periphyton Ash-Free dry weight (gm)
1.2
0.9
0.6
0.3
0.0
1
10
20
1
10
20
1
10
20
1
June
July
August

2 meters both years. Five meter slides often contained many Hydra, especially during June and early July 1970.

Periphyton standing crop during early June 1970 was significantly less than during the same period 1969. After aeration began during 1970, periphyton standing crops increased to over 0.030 gm/day during July. It then declined to 0.016 gm/day during early August, and increased a second time to 0.025 gm/day by late August. These changes closely approximate changes in the phytoplankton, both in changes of relative abundance, as well as times of maxima and minima.

Total accumulative periphyton standing crop increased throughout the summer both years. These increases were almost linear between June and September (Figure 40). An average maximum value of over 0.7 gm was attained by August 21, 1969. Although accumulated periphyton was less during June 1970 compared to June 1969, it was significantly greater during the remainder of the summer 1970. Total accumulated periphyton reached a 1.2 gm maxima by August 21, 1970. This was almost twice the 1969 maximum value.

Zooplankton

Only two sets of zooplankton samples were collected. One set was collected just before aeration began, June 11, 1970. The other set was collected after one month of aeration. Both sets were collected during daylight hours.

Before aeration began, zooplankters were mostly limited to depths above the oxygen depletion (Figure 41). Diaptomas adults, Bosmina, and Diaphanosoma were most abundant within or below the metalimnion. Over 85% of Diaptomas nauplii were found within one meter of the surface, and Daphnia pulex were scattered throughout the water column. After one month of aeration, the depth distributions of Diaptomas adults, Diaphanosoma and D. pulex were much changed. Diaptomas adults extended their maximum depth from 9 m to 18.6 m and their average depth from 4.5 m to 6.0 m. Diaphanosoma were most abundant after aeration near the surface and just off the bottom. Their depth distribution was much altered by aeration, but their average depths were about the same. D. pulex increased their average depth from 4.6 m before to 13.8 m after aeration. Over 80% of the Diaptomas nauplii were still found in the upper meter after aeration, and Bosmina had essentially the same depth distribution as before aeration.

More astonishing than the changes in depth distribution were the changes in population numbers. All zooplankters increased significantly (0.05 level) except Diaptomas nauplii (Table 4). Diaptomas nauplii decreased from a total of 71 to 13. Increases in D. pulex, Diaphanosoma and Bosmina were 88x, 21x and 3.1x respectively. No further information is available concerning the seasonal patterns of these zooplankters, other than for D. pulex. D. pulex became an important rainbow trout food item during the first week of July 1970 and remained so throughout the summer. It was also

Figure 41. Hemlock Lake zooplankton depth distributions three days before aeration began, and after one month of aeration. Oxygen and temperature profiles are shown for each date. ($\bar{x}$ = average depth.)

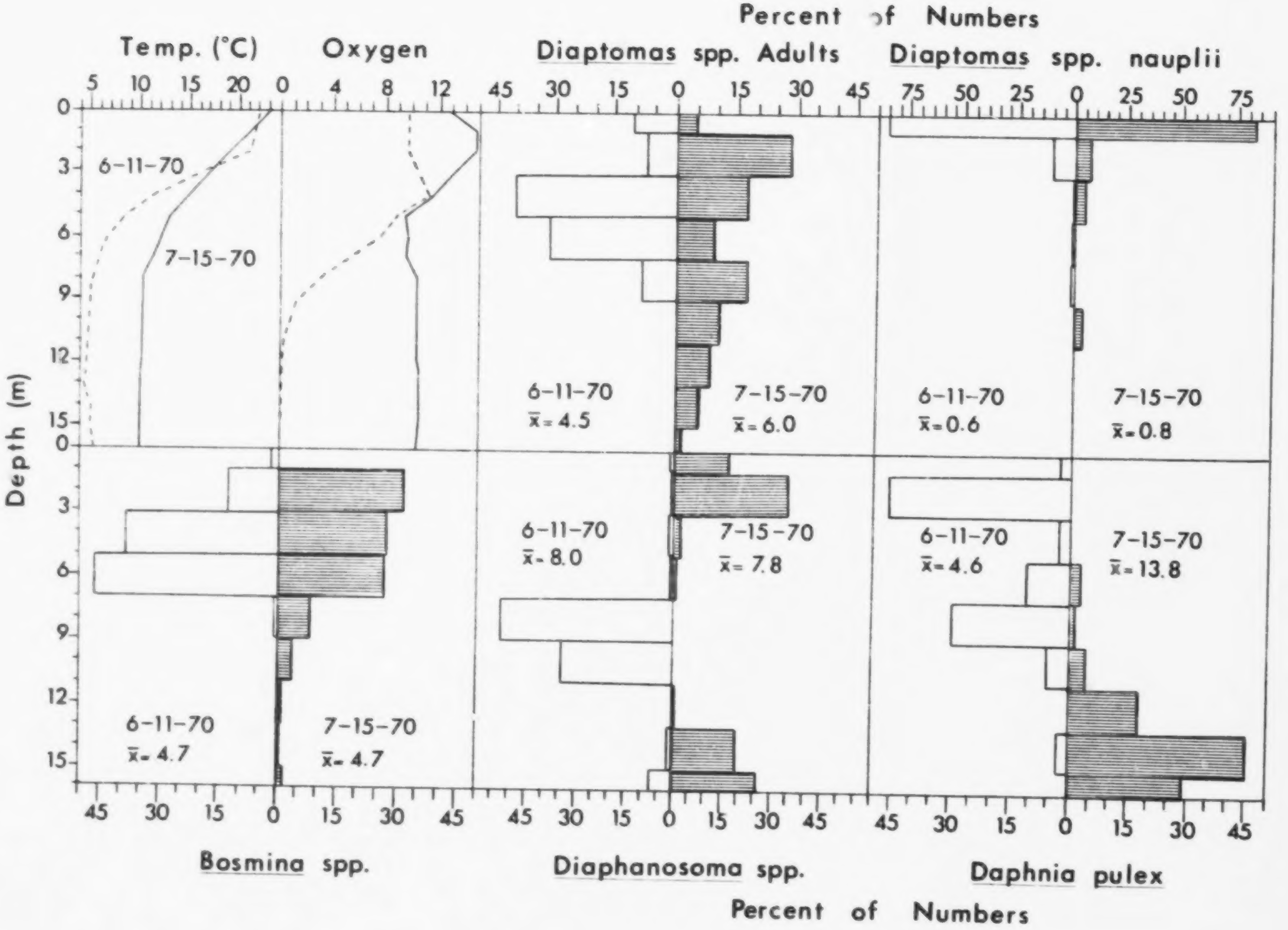

Percent of Numbers
Temp. (°C)
Oxygen
Diaptomas spp. Adults
Diaptomas spp. nauplii
5 10 15 20
0 4 8 12
45 30 15 0 15 30 45
75 50 25 0 25 50 75
Depth (m)
0 3 6 9 12 15
6-11-70
7-15-70
6-11-70
x̄ = 4.5
7-15-70
x̄ = 6.0
6-11-70
x̄ = 0.6
7-15-70
x̄ = 0.8
6-11-70
x̄ = 4.7
7-15-70
x̄ = 4.7
6-11-70
x̄ = 8.0
7-15-70
x̄ = 7.8
6-11-70
x̄ = 4.6
7-15-70
x̄ = 13.8
45 30 15 0 15 30 45
Bosmina spp.
Diaphanosoma spp.
Daphnia pulex
Percent of Numbers

Table 4. Hemlock zooplankton collected June 11 and July 15, 1970. Three samples were collected from each two meters depth interval. Totals represent the sum of the average number of zooplankters per liter from each depth. Total samples on each date = 27.

Organism	June 11, 1970			July 15, 1970		
	Total	95% C.I. on Total		Total	95% C.I. on Total	
Diaptomas spp. adults	162.	156.	168.	193.	188.	198.
Diaptomas spp. nauplii	71.	61.	81.	13.	11.	15.
Bosmina spp.	1,366.	1,254.	1,478.	4,228.	4,100.	4,456.
Diaphanosoma spp.	7.	6.	8.	157.	143.	171.
Daphnia pulex	2.	1.6	2.4	176.	160.	192.

commonly collected in the emergent insect traps after the first of July. These observations are not quantitative, but give some idea of _D_. _pulex_ relative abundance during the summer. It seemed to be most abundant about mid-July. On July 28th, over 75% of the individuals carried ephypia. This indicates adverse conditions, such as those associated with the large decline in the phytoplankton population at that time. Ephypia were not common thereafter, and _D_. _pulex_ seemed moderately abundant the remainder of the summer.

Zoobenthos

The three most important zoobenthos taxa in Hemlock, not including craybish, are the Chironomidae, Anisoptera and the Chaoborinae (Table 5 and Figure 42). Together they comprise more than 75% of the biomass and more than 95% by numbers of the benthic macro-organisms. Seven other taxa comprise the remainder. Chironomids are numerically the most abundant, but Anisoptera have the largest biomass. These estimates of relative abundance are based on static measures, namely standing crop. If production rates were known, the relative composition of these groups may be much different.

At least 12 species of Chironomid midges were identified by D. R. Oliver (Canada Dept. of Agriculture), from emergent adult specimens (Table 6). Only four species were relatively abundant in the emergent samples: _Procladinus denticulatus_, _Tanypus_, _Tanytarsus_, and _Dicrotendipes_.

Table 5. Hemlock Lake zoobenthos collected during the summers 1969 and 1970 with an Ekman dredge. 125 dredge samples were taken each summer. Wet weights are shown.

	Total Weight				Total Numbers				Number of Samples Found In		Mean Number of Individuals/gram	
	1969		1970		1969		1970					
	Grams	Percent	Grams	Percent	Number	Percent	Number	Percent	1969	1970	1969	1970
Oligochaetes (microdriles)	0.00347	0.1	0.13473	6.5	4	0.2	267	6.1	4	33	1,153	1,982
Chironomid L.	0.32719	13.6	0.49652	23.9	1,459	60.9	2,401	54.7	72	98	4,459	4,836
Chironomid P.	0.03928	1.6	0.02301	1.1	32	1.3	80	1.8	19	32	815	3,477
Amphipods	0.00044	0.0	0.00069	0.0	3	0.1	3	0.1	3	3	6,818	4,348
Dragonflies	0.83401	34.6	0.97448	44.7	17	0.7	14	0.3	12	8	20	14
Damselflies	0.01013	0.4	0.00380	0.2	15	0.6	3	0.1	3	3	1,481	789
Mayflies	0.04548	1.9	0.02483	1.2	115	4.8	110	2.5	18	26	2,529	4,430
Chaoborus spp. L.	0.040378	16.7	0.31419	15.1	535	22.3	1,336	30.4	78	88	1,325	4,252
Chaoborus spp. P.	0.13232	5.5	0.04911	2.4	91	3.8	77	1.8	41	39	688	1,568
Heleidae	0.05514	2.3	0.02370	1.1	96	4.0	96	2.2	25	32	1,741	4,051
Trichoptera	0.01608	0.7	0.00008	0.0	28	1.2	1	0.0	1	1	1,741	12,500
Tabaniid	0.00000	0.0	0.00024	0.0	0	0.0	1	0.0	0	1	--	4,167
Leeches	0.54629	22.6	0.02961	1.4	1	0.0	1	0.0	1	1	2	34
Total	2.41360	100.0	2.07497	100.0	2,396.	100.0	4,390.	100.0				

Figure 42. Hemlock Lake zoobenthos percent composition during the summers 1969 and 1970. Percent of wet weight and percent of number are shown for each taxa. Total weights and total numbers collected each summer are also shown. Samples from dredge collections only.

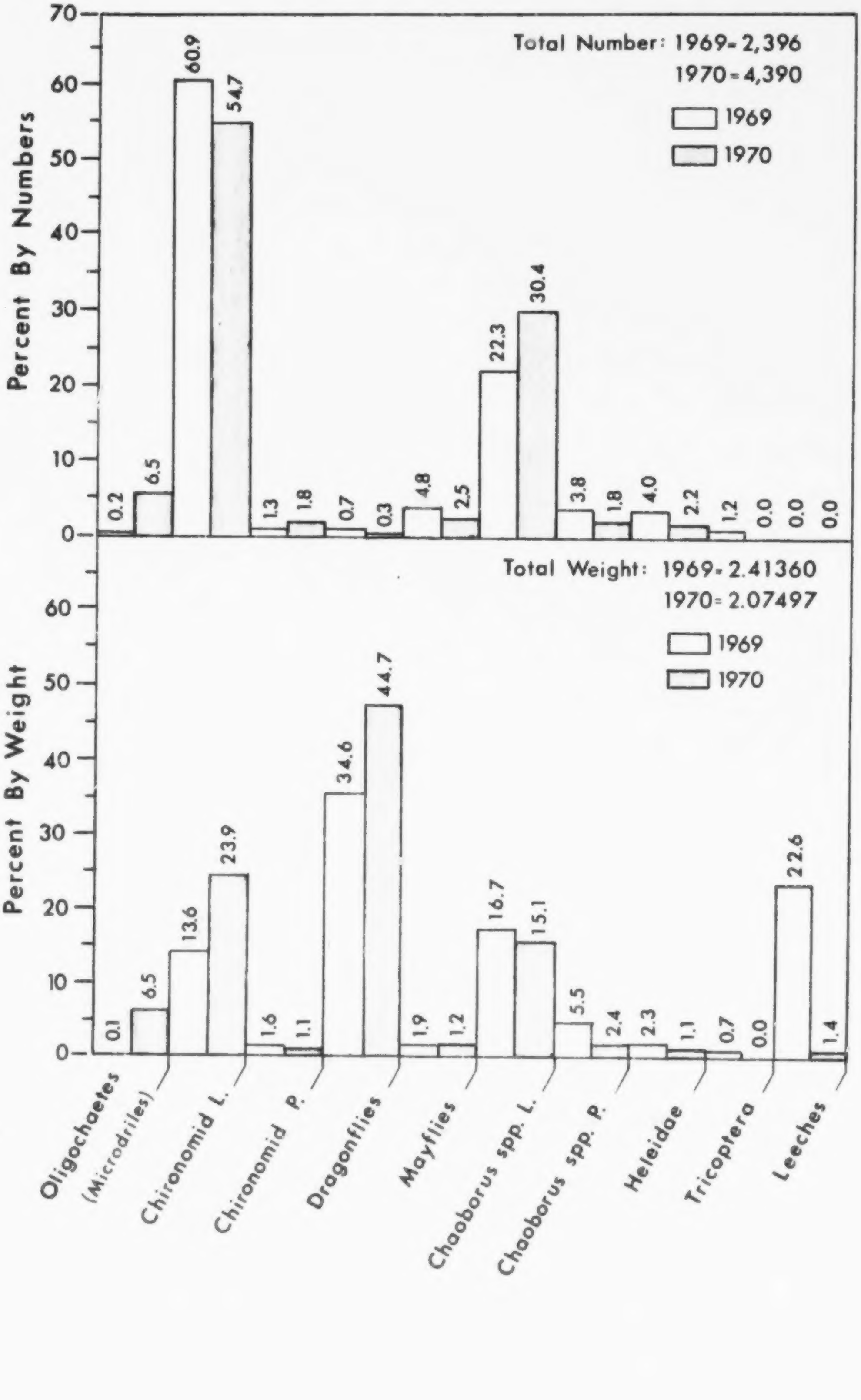

Total Number: 1969=2,396
1970=4,390
1969
1970
Percent By Numbers
70
60
50
40
30
20
10
0
0.2
6.5
60.9
54.7
1.3
1.8
0.7
0.3
4.8
2.5
22.3
30.4
3.8
1.8
4.0
2.2
1.2
0.0
0.0
0.0
Total Weight: 1969=2.41360
1970=2.07497
1969
1970
Percent By Weight
60
50
40
30
20
10
0
0.1
6.5
13.6
23.9
1.6
1.1
34.6
44.7
1.9
1.2
16.7
15.1
5.5
2.4
2.3
1.1
0.7
0.0
22.6
1.4
Oligochaetes
(Microdriles)
Chironomid L.
Chironomid P.
Dragonflies
Mayflies
Chaoborus spp. L.
Chaoborus spp. P.
Heleidae
Tricoptera
Leeches

Table 6 . Emergent midge adults collected from 600 samples during 1969, and 650 samples during 1970. All specimens are from Hemlock Lake and were collected in emergent insect traps.

	1969				1970			
	Total Number	Percent of Total Number	No. of Samples	No. of Dates	Total Number	Percent of Total Number	No. of Samples	No. of Dates
Family - Chironomidae (Tendipedidae)								
Subfamily - Pelopiinae (Tanypodinae)								
Procladius (Psilotanypus) bellus	27	6	20	16	30	3	21	19
P. (s.s.) denticulatus	76	18	34	26	261	25	80	48
Tanypus spp. 1/	43	10	26	19	86	8	57	35
Subfamily - Chironominae (Tendipedinae)								
Endochironomus spp. 1/	0	0	0	0	2	1	2	2
Zavrelia spp.	2	1	2	2	4	1	3	3
Chironomus spp. 2/	1	1	1	1	7	1	6	5
C. (s.s.) staegeri	0	0	0	0	1	1	1	1
Polypedilum (Pentapedilum) sordens	4	1	4	4	44	4	14	11
Cladotanytarsus viridiventris	2	1	2	2	0	0	0	0
Tanytarsus spp.	117	27	53	37	86	8	32	27
Dicrotendipes spp.	105	24	42	31	231	22	37	24
Paratendipes albimanus	6	1	6	6	2	1	2	2
Family - Culicidae								
Subfamily - Chaoborinae								
Chaoborus flavicans	47	11	35	21	84	8	51	29
C. punctipennis	0	0	0	0	212	20	57	22
Totals	430	100	225		1,050	100	363	

1/ Probably a new species

2/ C. tentans identified from larvae only

Procladius and Tanypus are generally thought to be predaceous while the other two genera are generally thought to be omnivorous, feeding mostly on plant material and detritus. One species each of Tanypus and Endochironomus may be new species. Positive identification of many of the species was impossible because of the small sample sizes with few males. Only 430 adult midges were collected during 1969, and 1,050 during 1970. These values are very low considering 1,250 emergent trap sets were made. Only 225 of 600 samples contained any emergent midges during 1969, and 363 of 650 samples contained emergent midges during 1970.

The relative abundance of the emergent midge species may not reflect their actual relative abundance in the lake. Many species have peak emergence in May (Miller, 1941), but we did not begin our collections until mid-June. Chironomus tentans was collected as larvae, but not as adults. This species appeared relatively abundant in the hypolimnion after aeration.

During 1969, most of the Chironomid larvae were restricted to 9 meters or less by hypolimnion stagnation (Figures 43 and 44). Less than five percent were found between 9 and 15 meters, and none were ever collected between 15 meters and maximum depth. Larvae living in deep water were generally larger than the shallow water larvae. For example, on September 6, 1969 five percent of the larvae by number were found between 9 and 15 meters, but 15 percent by weight were in this interval.

Figure 43. Hemlock Lake Chironomid larvae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

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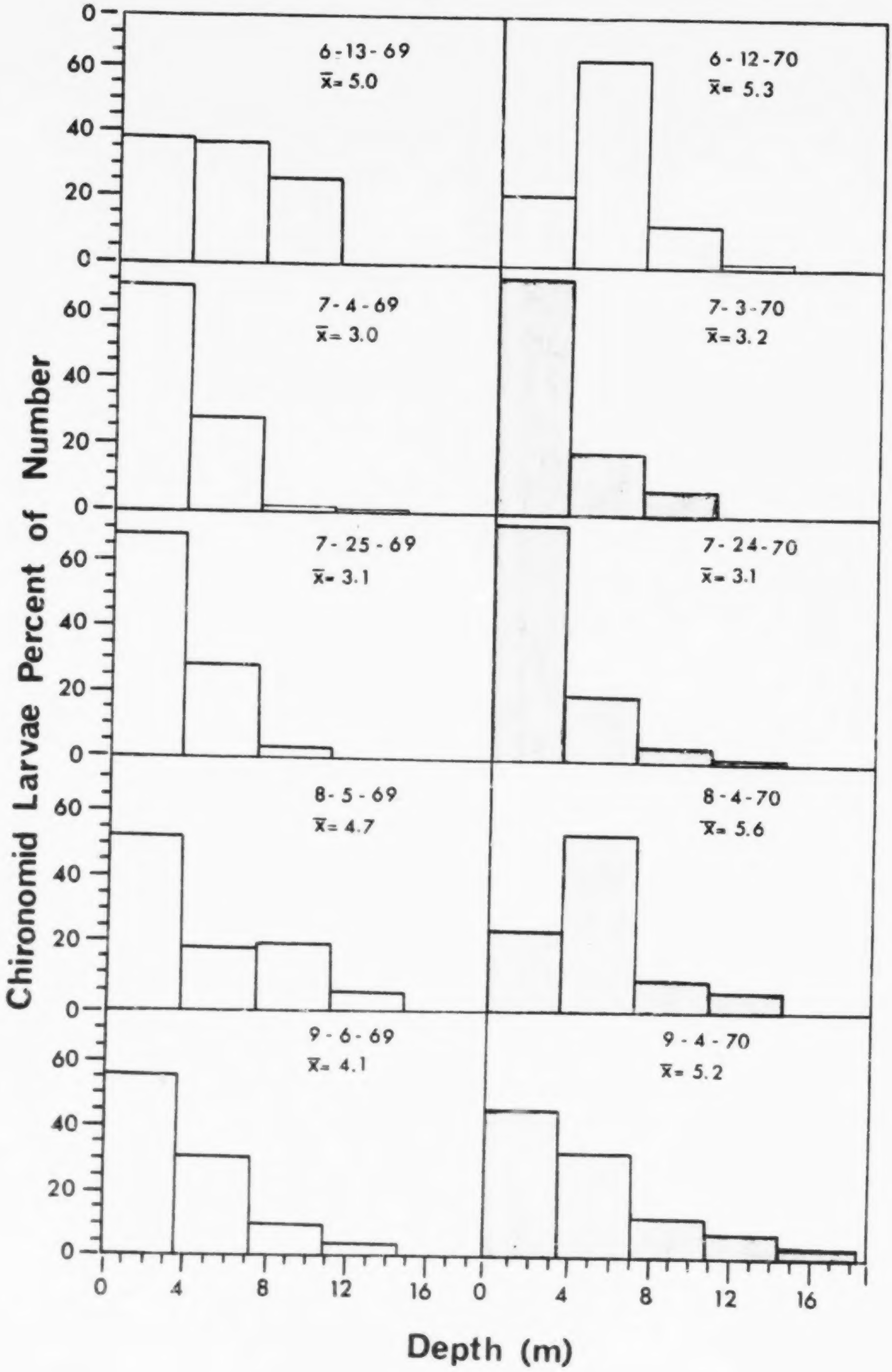
6-13-69
x̄= 5.0
6-12-70
x̄= 5.3
7-4-69
x̄= 3.0
7-3-70
x̄= 3.2
7-25-69
x̄= 3.1
7-24-70
x̄= 3.1
8-5-69
x̄= 4.7
8-4-70
x̄= 5.6
9-6-69
x̄= 4.1
9-4-70
x̄= 5.2
Chironomid Larvae Percent of Number
0
20
40
60
Depth (m)
0
4
8
12
16

Figure 44. Hemlock Lake Chironomid larvae depth distribution as percent of wet weight during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

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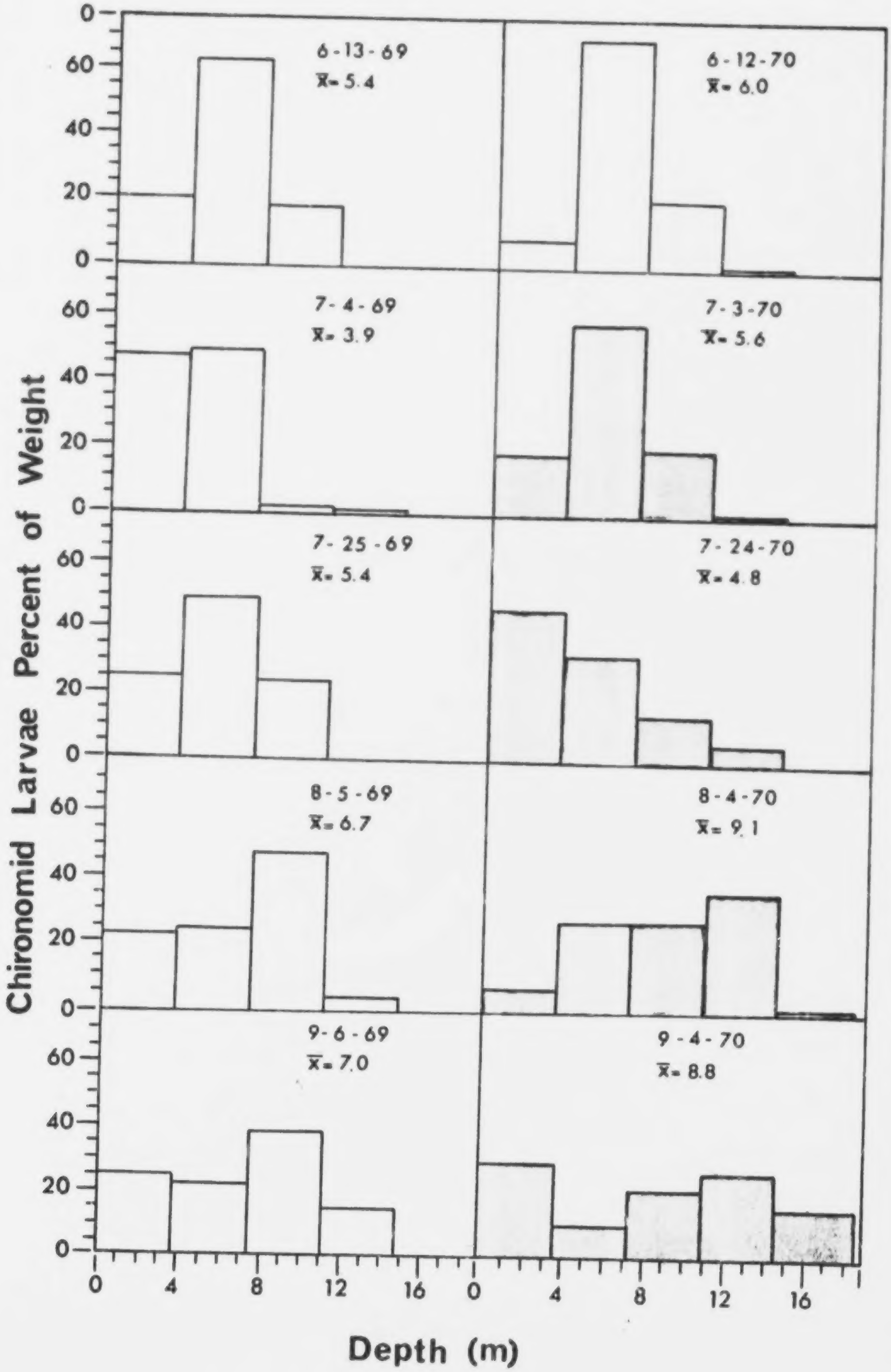


6-13-69
x̄= 5.4
6-12-70
x̄= 6.0
7-4-69
x̄= 3.9
7-3-70
x̄= 5.6
7-25-69
x̄= 5.4
7-24-70
x̄= 4.8
8-5-69
x̄= 6.7
8-4-70
x̄= 9.1
9-6-69
x̄= 7.0
9-4-70
x̄= 8.8
Chironomid Larvae Percent of Weight
0
20
40
60
0
4
8
12
16
Depth (m)

Although substantial numbers and biomass of Chironomid larvae were present below 7 meters during 1969, very few emerged from these depths. Pupae were collected below 7 meters only during August 5, 1969, and then only between 7.5 and 11 meters (Figures 45 and 46). Emergent adults were most abundant above 4 meters depth and were collected below 8 meters only during late July (Figure 47). Emergence in the 0 to 4 meter interval ranged between 70% and 95%. Relatively more midges emerged from 0 to 4 meters during June than during August. Miller (1941) reports this same situation in Costello Lake, Ontario, Canada.

Total emergence during 1969 was generally less than $3. \times 10^5$ individuals/week (Figure 48). Emergence does not have any obvious pattern, due in part to its composite nature. The species composition changes from week to week, but Tanytarsus and Dicrotendipes were generally most abundant. These two midges comprised 51% of the total emergence during 1969.

Chironomid larvae gradually extended their depth distribution after aeration began June 14, 1970 (Figures 43 and 44). Less than 1% by number or 2% by weight were found below 11 meters on July 3rd. By September 4th more than 15% by number and 40% by weight were found below 11 meters. Chironomid larvae were first taken from dredge samples near maximum depth on August 4th. Larvae were observed in the emergent trap samples before this date, however. By September 4th 5% by number and 15% by weight were present between

Figure 45. Hemlock Lake Chironomid pupae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

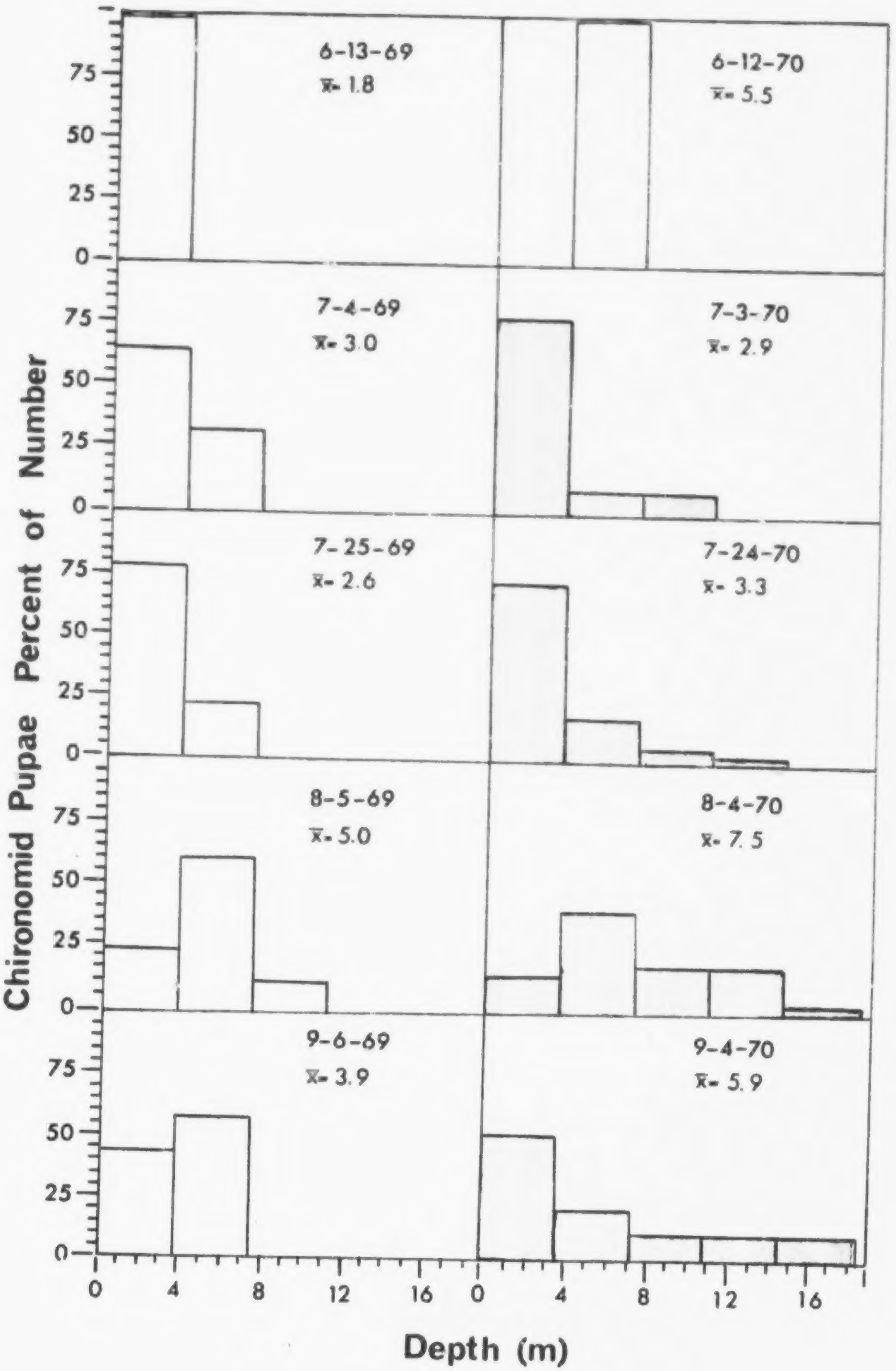

6-13-69
x̄= 1.8
6-12-70
x̄= 5.5
7-4-69
x̄= 3.0
7-3-70
x̄= 2.9
7-25-69
x̄= 2.6
7-24-70
x̄= 3.3
8-5-69
x̄= 5.0
8-4-70
x̄= 7.5
9-6-69
x̄= 3.9
9-4-70
x̄= 5.9
0
25
50
75
Chironomid Pupae Percent of Number
0
4
8
12
16
Depth (m)

Figure 46. Hemlock Lake Chironomid pupae depth distribution as percent of wet weight during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

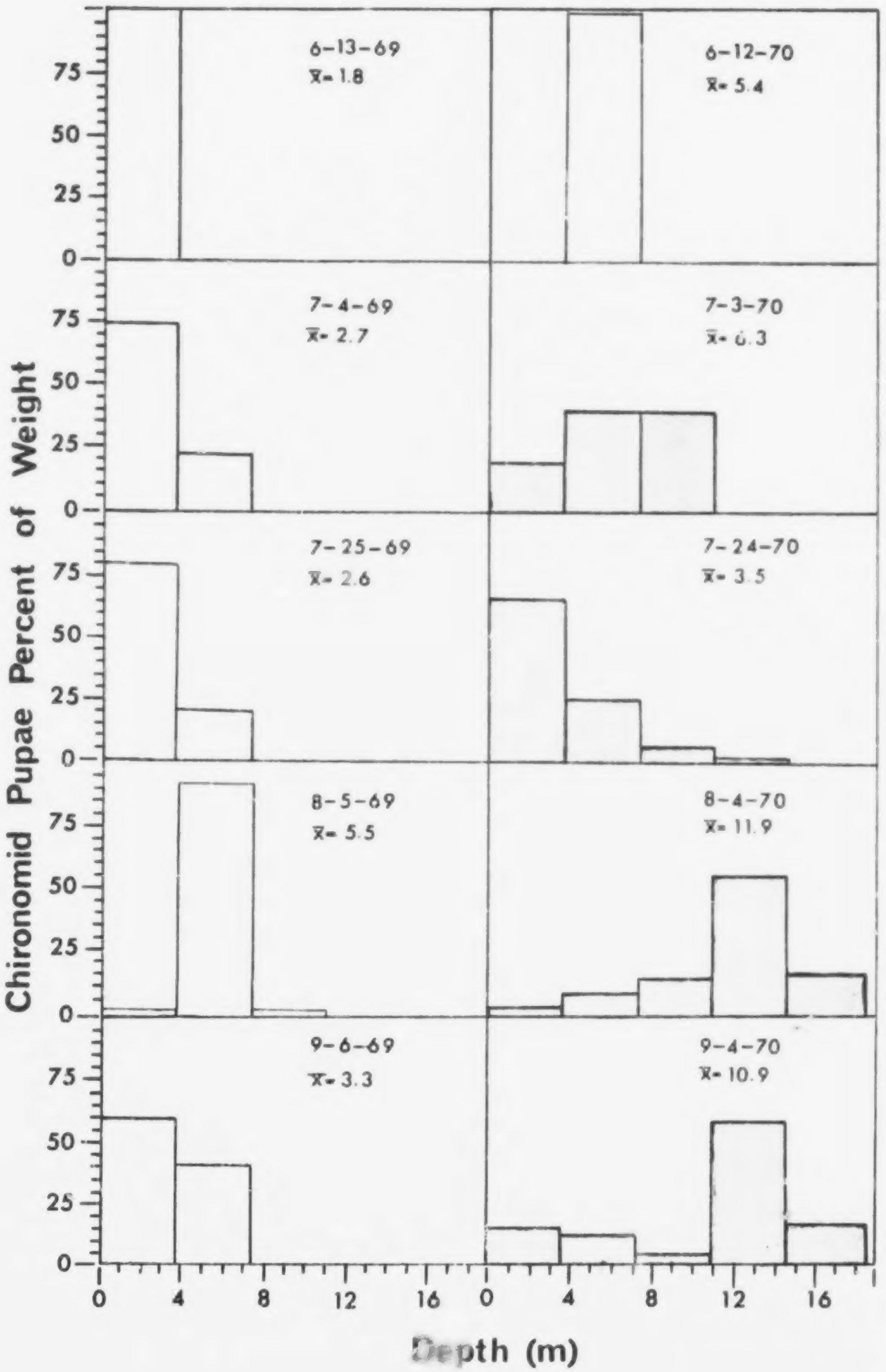

6-13-69
x̄= 1.8
6-12-70
x̄= 5.4
7-4-69
x̄= 2.7
7-3-70
x̄= 6.3
7-25-69
x̄= 2.6
7-24-70
x̄= 3.5
8-5-69
x̄= 5.5
8-4-70
x̄= 11.9
9-6-69
x̄= 3.3
9-4-70
x̄= 10.9
0
25
50
75
Chironomid Pupae Percent of Weight
0
4
8
12
16
Depth (m)

Figure 47. Total midge emergence from Hemlock Lake by depths during the summers 1969 and 1970. Aeration occurred continuously between June 14 and September 7, 1970. Totals include Chaoborinae and Chironomid midges from emergence traps only.

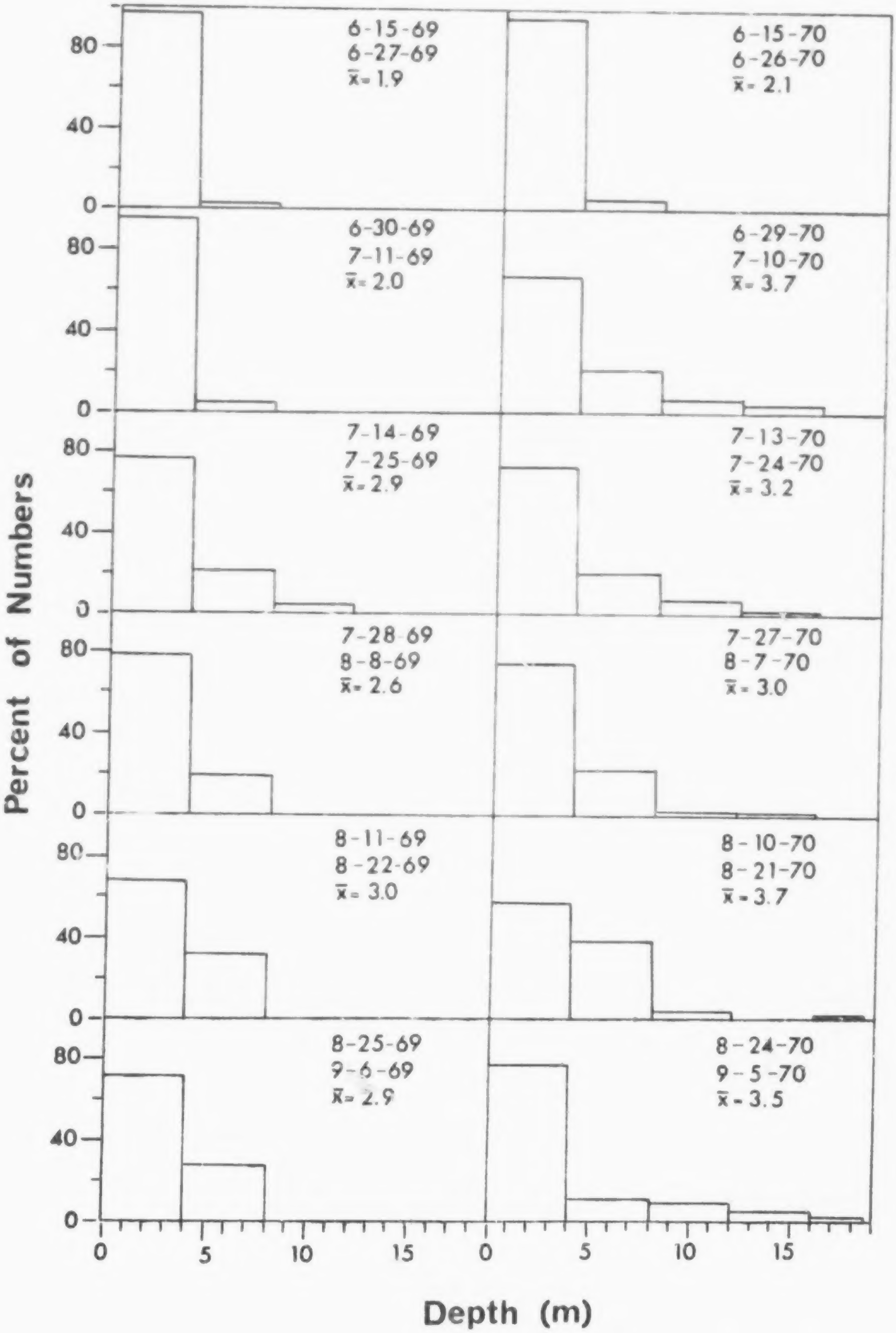
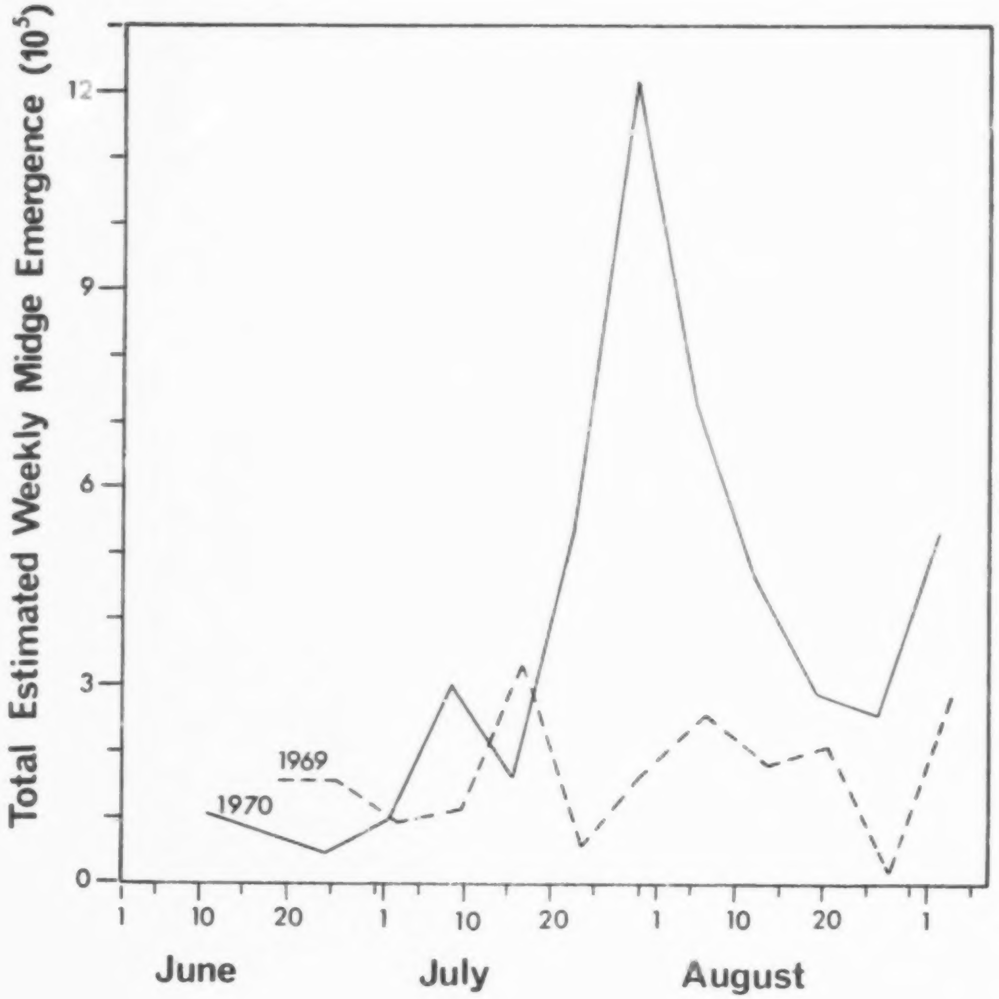

6-15-69
6-27-69
x̄= 1.9
6-15-70
6-26-70
x̄= 2.1
6-30-69
7-11-69
x̄= 2.0
6-29-70
7-10-70
x̄= 3.7
7-14-69
7-25-69
x̄= 2.9
7-13-70
7-24-70
x̄= 3.2
7-28-69
8-8-69
x̄= 2.6
7-27-70
8-7-70
x̄= 3.0
8-11-69
8-22-69
x̄= 3.0
8-10-70
8-21-70
x̄= 3.7
8-25-69
9-6-69
x̄= 2.9
8-24-70
9-5-70
x̄= 3.5
Percent of Numbers
0
40
80
Depth (m)
0
5
10
15

Figure 48. Total estimated weekly midge emergence from Hemlock Lake during the summers 1969 and 1970. Totals include Chaoborinae and Chironomid midges from emergence traps only. Aeration occurred continuously between June 14 and September 7, 1970.


Total Estimated Weekly Midge Emergence (10^5)
12
9
6
3
0
1
10
20
1
10
20
1
10
20
1
June
July
August
1969
1970

14.5 m and maximum depth. Total numbers of Chironomid larvae increased greatly during aeration. An estimated $2.5x10^7$ maximum number were present during 1970, compared to a $1.5x10^7$ maximum for 1969 (Figure 49). Biomass also increased during aeration to a 44 gm maxima during July 1960, compared to a 38 gm maxima during 1969. There was a 65% increase in total number collected during 1970 compared to 1969, and a 52% increase in weight (Table 5).

Chironomid emergence during 1970 also gradually extended into deeper water at about the same rate as the larvae. Pupal concentrations by numbers were always greatest above 7 meters, but much larger pupae were collected below 11 meters on August 4th and September 4th than in shallower water (Figures 45 and 46). Total numbers of chironomid pupae were much greater during 1970. An estimated maxima of $12x10^5$ were present during July 1970 compared to a $3x10^5$ maxima for 1969 (Figure 50). Interestingly enough, total biomass was essentially the same both summers, indicating the 1970 pupae were smaller. Total number of pupae collected during 1970 increased 250% compared to 1969, but total weight decreased 41% (Table 5). Total emergent adults were always most abundant between 0 and 4 meters (Figure 47). More than 5% of the total emergence between June 29th and July 10th occurred in the 12 m to 16 m interval. Emergence from maximum depth occurred during July, but was not abundant until mid-August. Adults almost never emerged below 8 meters during 1969.

Figure 49. Total estimated Chironomid larvae number and wet weight in Hemlock Lake during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.

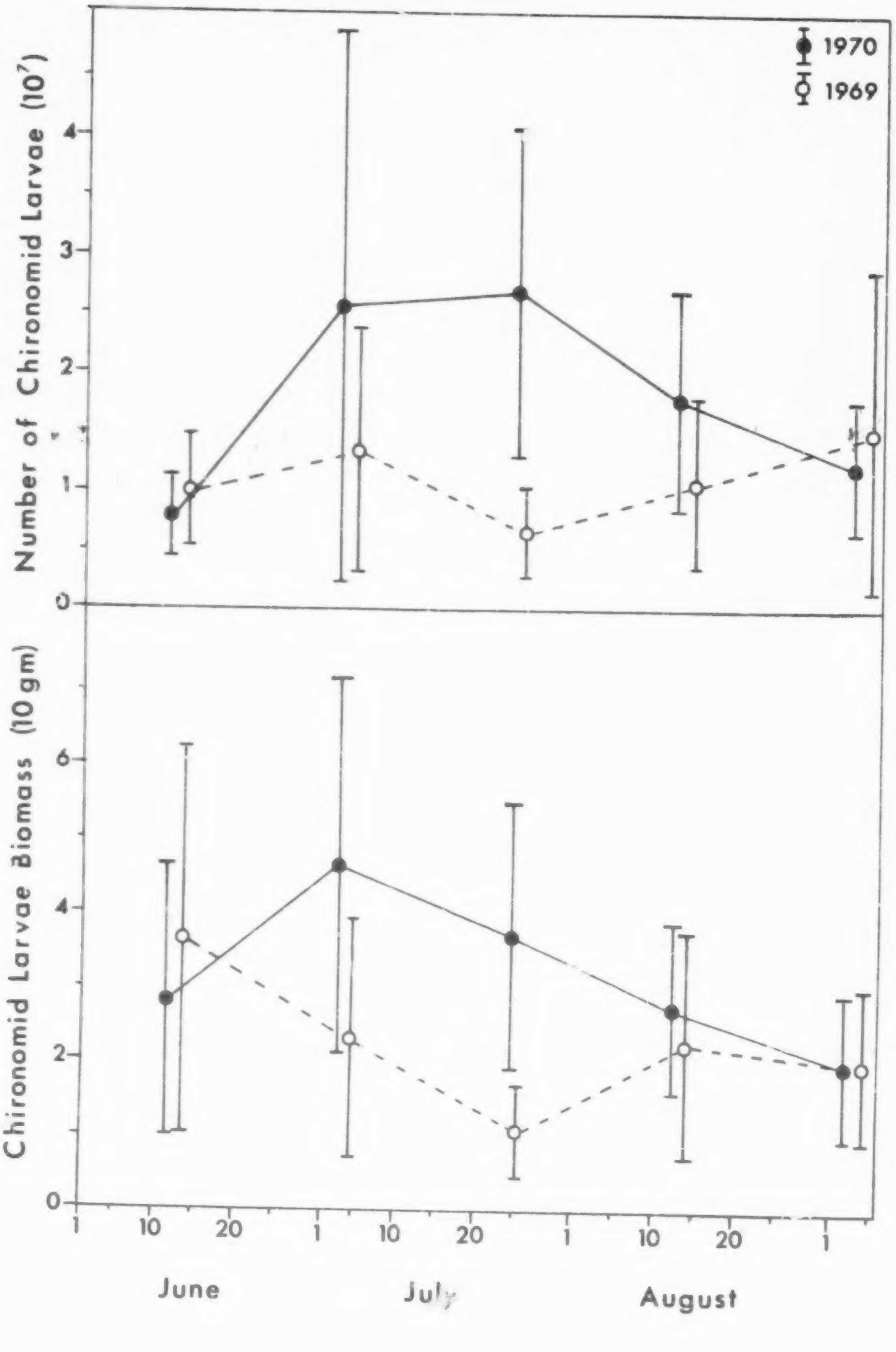

1970
1969
Number of Chironomid Larvae (10⁷)
0
1
2
3
4
Chironomid Larvae Biomass (10 gm)
0
2
4
6
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 50. Total estimated Chironomid pupae number and wet weight in Hemlock Lake during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.

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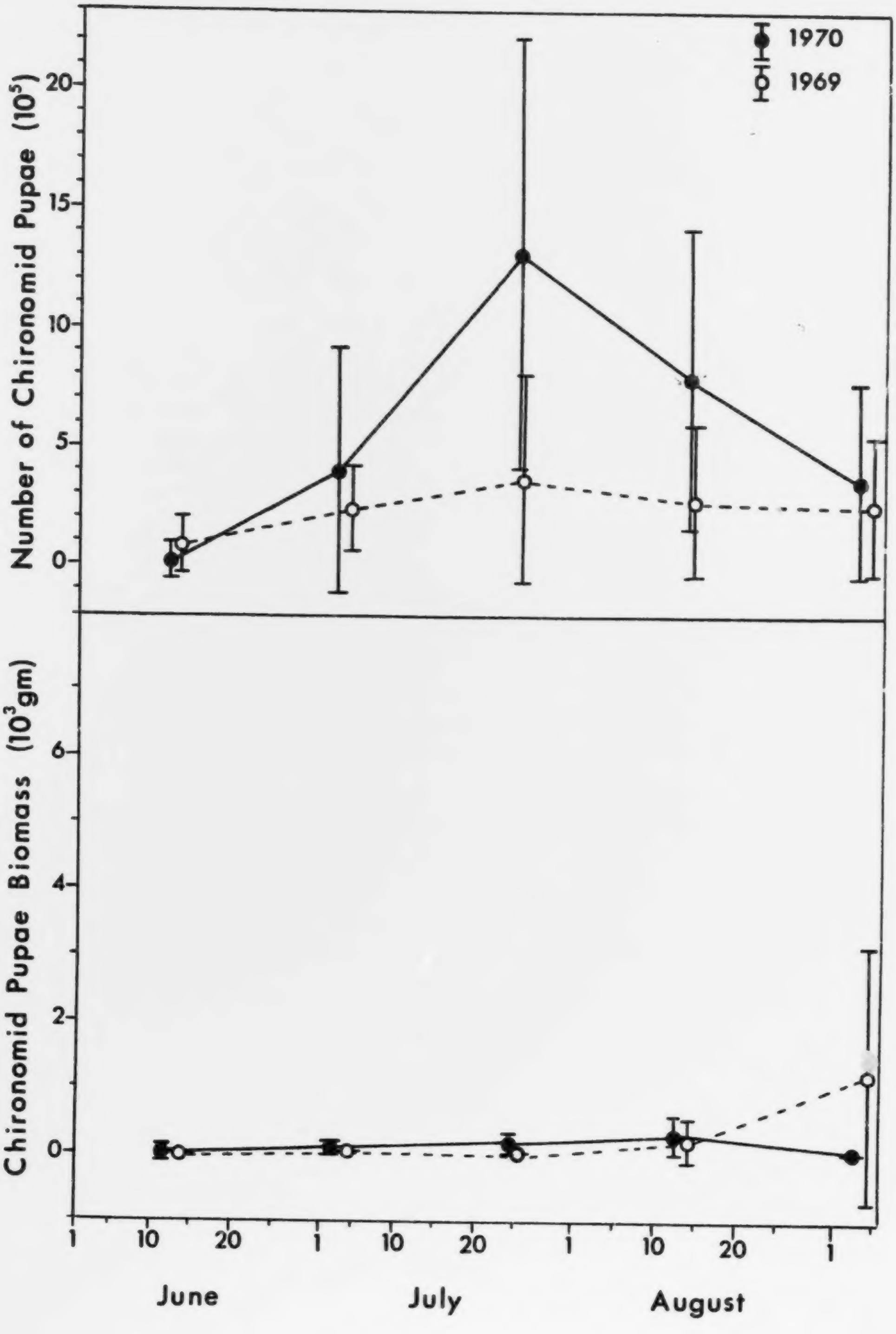


1970
1969
Number of Chironomid Pupae (10^5)
0
5
10
15
20
Chironomid Pupae Biomass (10^3gm)
0
2
4
6
1
10
20
1
10
20
1
10
20
1
June
July
August

Procladius denticulatus never emerged below 12 meters during 1969 (Figure 51). After aeration it emerged below 16 m in early July and was more numerous below 8 m during late July and early August. During 1969 its peak emergence occurred during August, with no individuals observed before July 10th (Figure 52). During 1970 its peak emergence occurred about July 15th and individuals were observed all summer. Total individuals observed in the traps was 261 for 1970 compared to 76 for 1969.

Tanypus never emerged below 4 m during 1969, but emerged below 16 m during August 1970 (Figure 51). Its emergence pattern was rather uniform during 1969, but during 1970 it reached peak values during late July and late August. About twice as many *Tanypus* emerged during 1970 compared to 1969 (Figure 51).

Dicrotendipes modestus emerged from slightly deeper depths after aeration began (Figure 51). During 1969 its emergence was limited to less than 8 m, but during August 1970 it emerged below 8 m. Almost twice as many emerged during 1970, compared to 1969 (Figure 52).

Tanytarsus were almost entirely restricted between 0 and 4 m both years. Only one emergent adult was collected between 4 and 8 m during 1969, and none were collected below 8 m. During 1970 one emergent adult was collected between 4 and 8 m and one between 8 and 12 m. No adults were collected below 12 m during 1970.

Figure 51. Depth emergence of selected insects from Hemlock Lake during the summers 1969 and 1970. White areas during the sampling periods represent no observed emergence. A= *Procladius denticulatus*, B= *Tanypus*, C= *Dicrotendipes*, D= Mayflies (Ephemeroptera). Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.

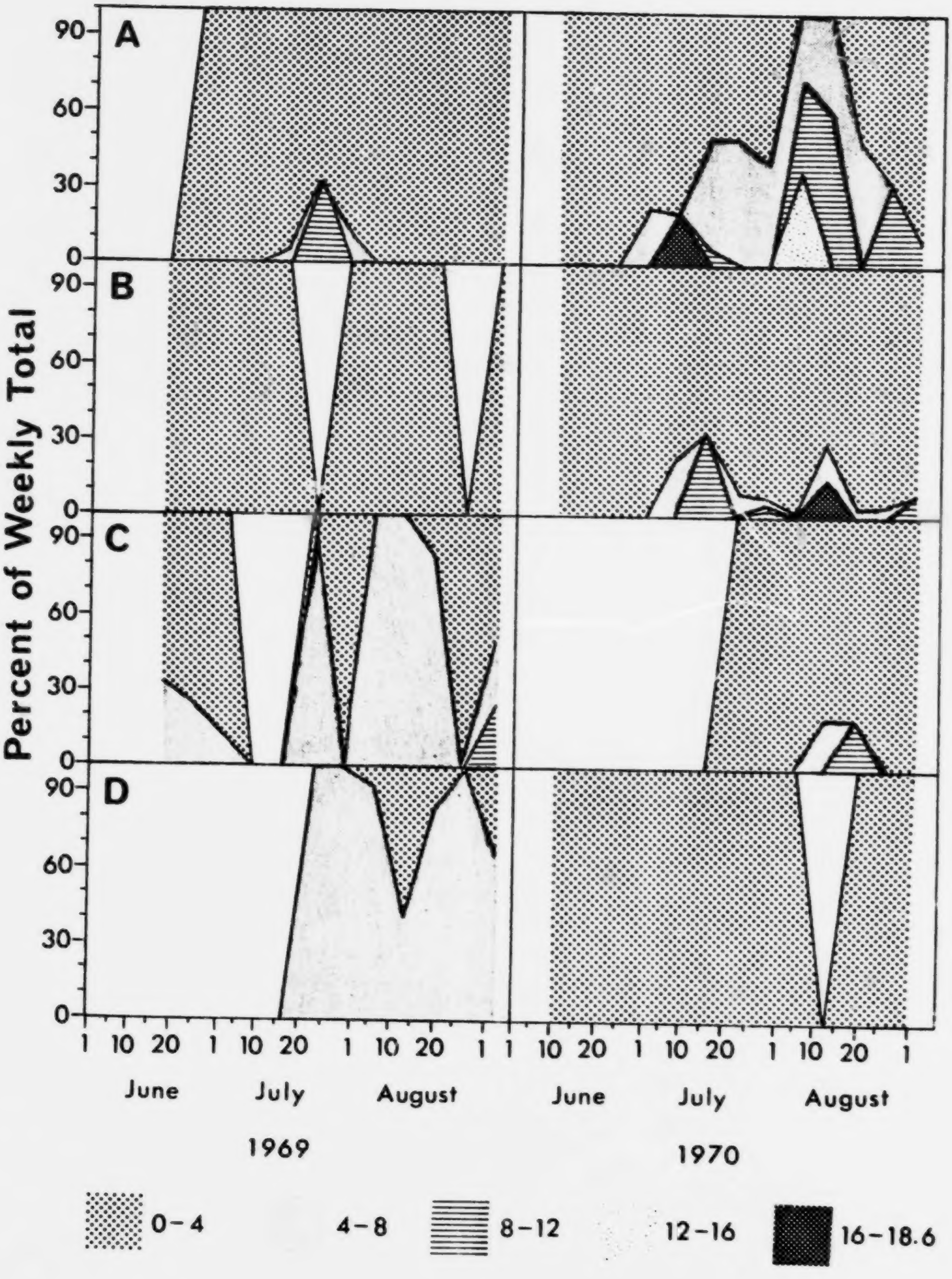
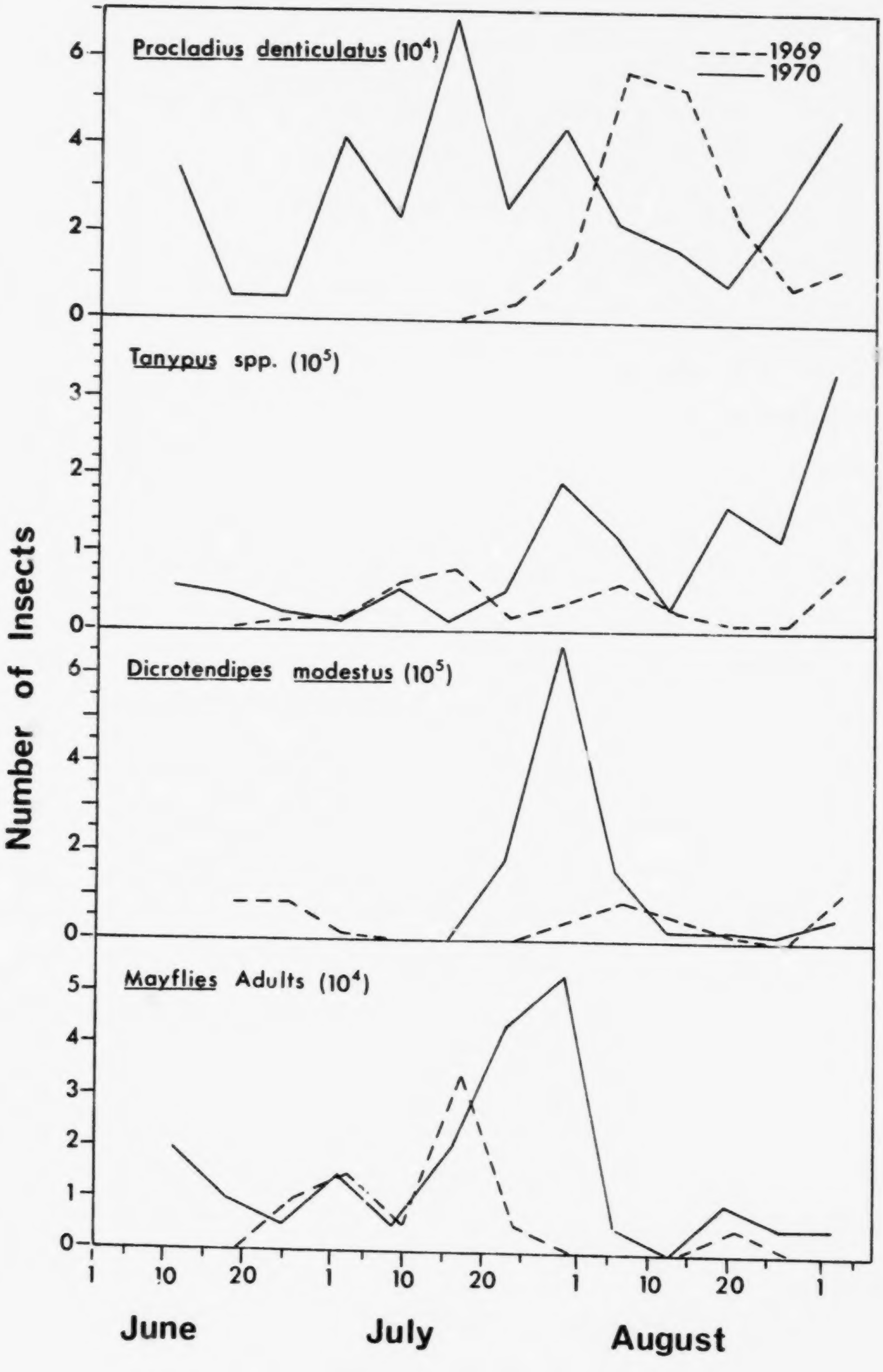

A
B
C
D
Percent of Weekly Total
90
60
30
0
1 10 20 1 10 20 1 10 20 1
June
July
August
1969
1 10 20 1 10 20 1 10 20 1
June
July
August
1970
0-4
4-8
8-12
12-16
16-18.6

Figure 52. Total estimated emergences from Hemlock Lake. Samples from emergence traps only. Aeration occurred continuously between June 14 and September 7, 1970.


Procladius denticulatus (10^4)
1969
1970
6
4
2
0
Tanypus spp. (10^5)
3
2
1
0
Dicrotendipes modestus (10^5)
6
4
2
0
Mayflies Adults (10^4)
5
4
3
2
1
0
Number of Insects
1
10
20
1
10
20
1
10
20
1
June
July
August

Total weekly emergence was much greater during 1970 compared to 1969. A maximum of over 12×10^5 individuals emerged about August 1, 1970 compared to a 3×10^5 maximum for the summer 1969. One thousand fifty adults were collected from the traps during 1970 compared to 430 for 1969. The greatest percentage increase occurred with the *Chaoborus*. *Chaoborus* comprised 11% of the total emergence during 1969, but 28% during 1970 (Table 6).

Two species of Chaoborinae were identified by B. V. Peterson and D. M. Wood (Canada Dept. of Agriculture). *Chaoborus flavicans* was present both years, comprising 11% of the emergence during 1969 and 8% during 1970. *C. punctipennis* was not observed during 1969, but comprised 20% of the emergence during 1970. This large increase in emergent adults during 1970 and species shift is reflected by an increase in numbers of larvae and decreased average size. *Chaoborus* larvae collected by the dredge totaled 535 during 1969 and 1,336 during 1970 (Table 5). Average size of those larvae decreased from 1,325/gm during 1969 to 4,252/gm during 1970. This decrease is probably due to two factors: increased proportions of *C. punctipennis* and increased population size. *C. punctipennis* is smaller than *C. flavicans*. More than twice as many *C. punctipennis* adults were collected during 1970 compared to *C. flavicans*. No *C. punctipennis* adults were observed during 1969.

Increased population size will result initially in larger numbers of the smaller instars. Instars three and four are essentially the only ones collected by the dredge. Instars three and four were usually the only ones collected in the emergence traps, but instars one and two were also occasionally captured. Chaoborus larvae collected by the dredge reached a maximum estimated population size of $20x10^6$ individuals during July 1970 (Figure 53). Their 1969 maximum was $6x10^6$. Maximum total biomass was only slightly greater during 1970, however. Total numbers increased 250% during 1970 compared to 1969, but total weight decreased 22%. Chaoborus larvae comprised 22.3% of the macro-zoobenthos by number during 1969 and 30.4% during 1970 (Figure 42). However, the percent of Chaoborus larvae in the zoobenthos biomass decreased from 16.7% during 1969 to 15.1% during 1970.

Much lower Chaoborus larvae and pupae population sizes were estimated from the emergent insect trap samples (Figures 53, 54 and 55). A maximum larval population size of $48x10^5$ was estimated from the traps during July 1970, compared to $20x10^6$ from the dredge samples. By their very nature, the emergent trap samples are not expected to quantitatively sample the larval population. Larvae that live in the mud part of the day, but do not migrate during the sampling period will not enter the traps. Work by Roth (1968) indicates that some larvae do not migrate everyday. The proportion migrating may also be related to temperature (Stahl, 1966). Furthermore, in lakes with pronounced oxygen deficits

Figure 53. Total estimated Chaoborus larvae number and wet weight in Hemlock Lake during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.

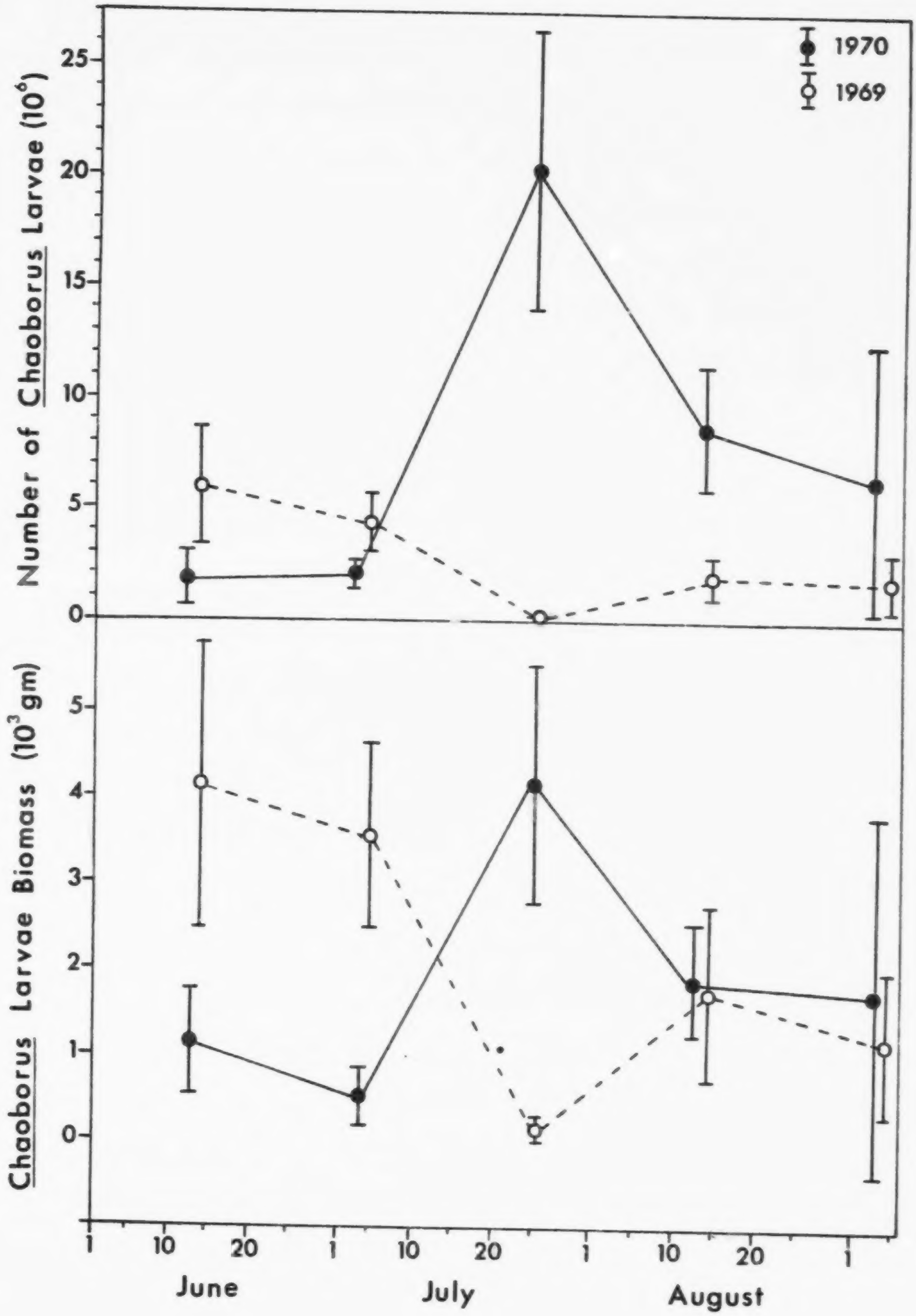

1970
1969
Number of Chaoborus Larvae (10⁶)
25
20
15
10
5
0
Chaoborus Larvae Biomass (10³ gm)
5
4
3
2
1
0
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 54. Total estimated Chaoborus pupae number and wet weight in Hemlock Lake during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.

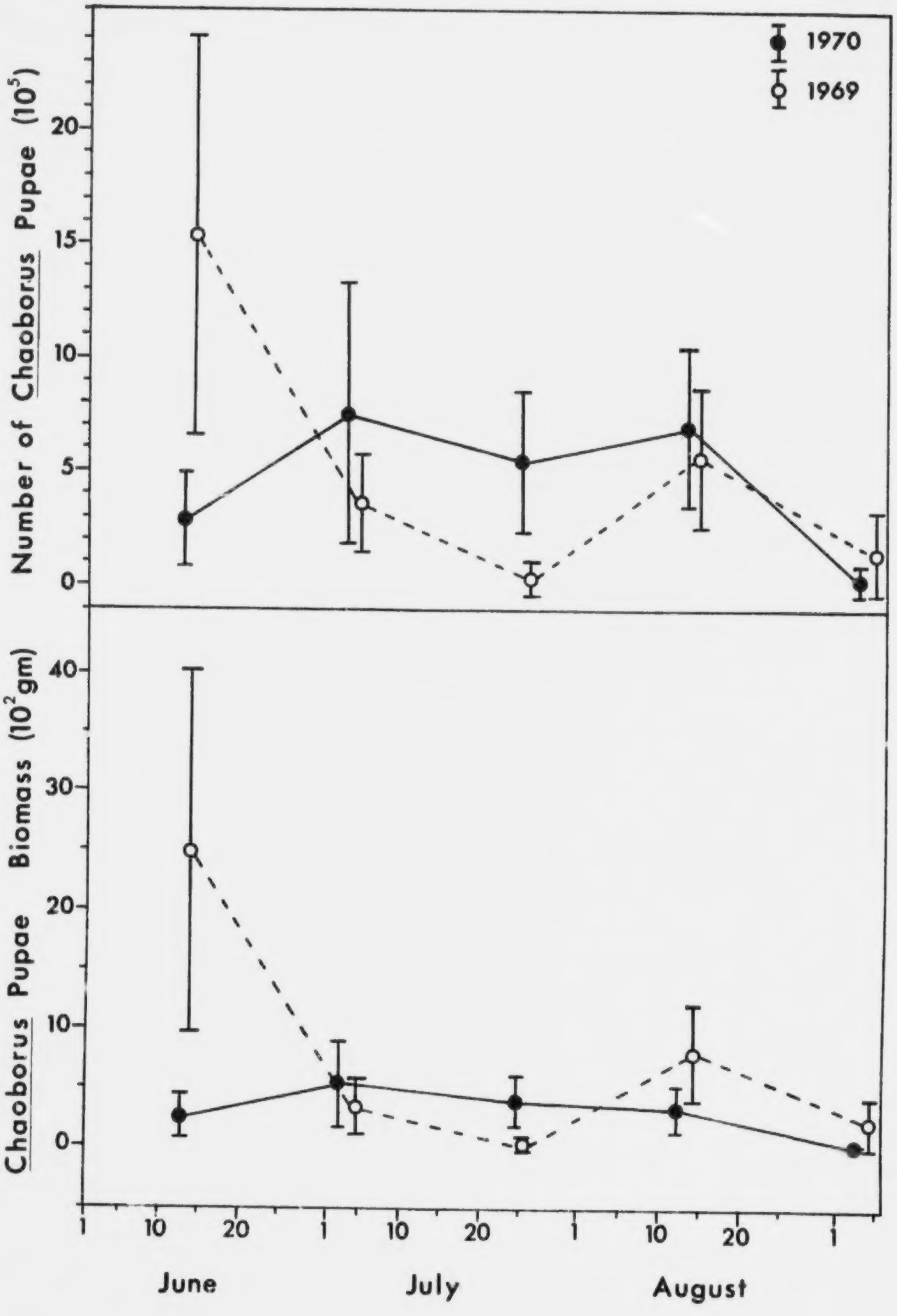
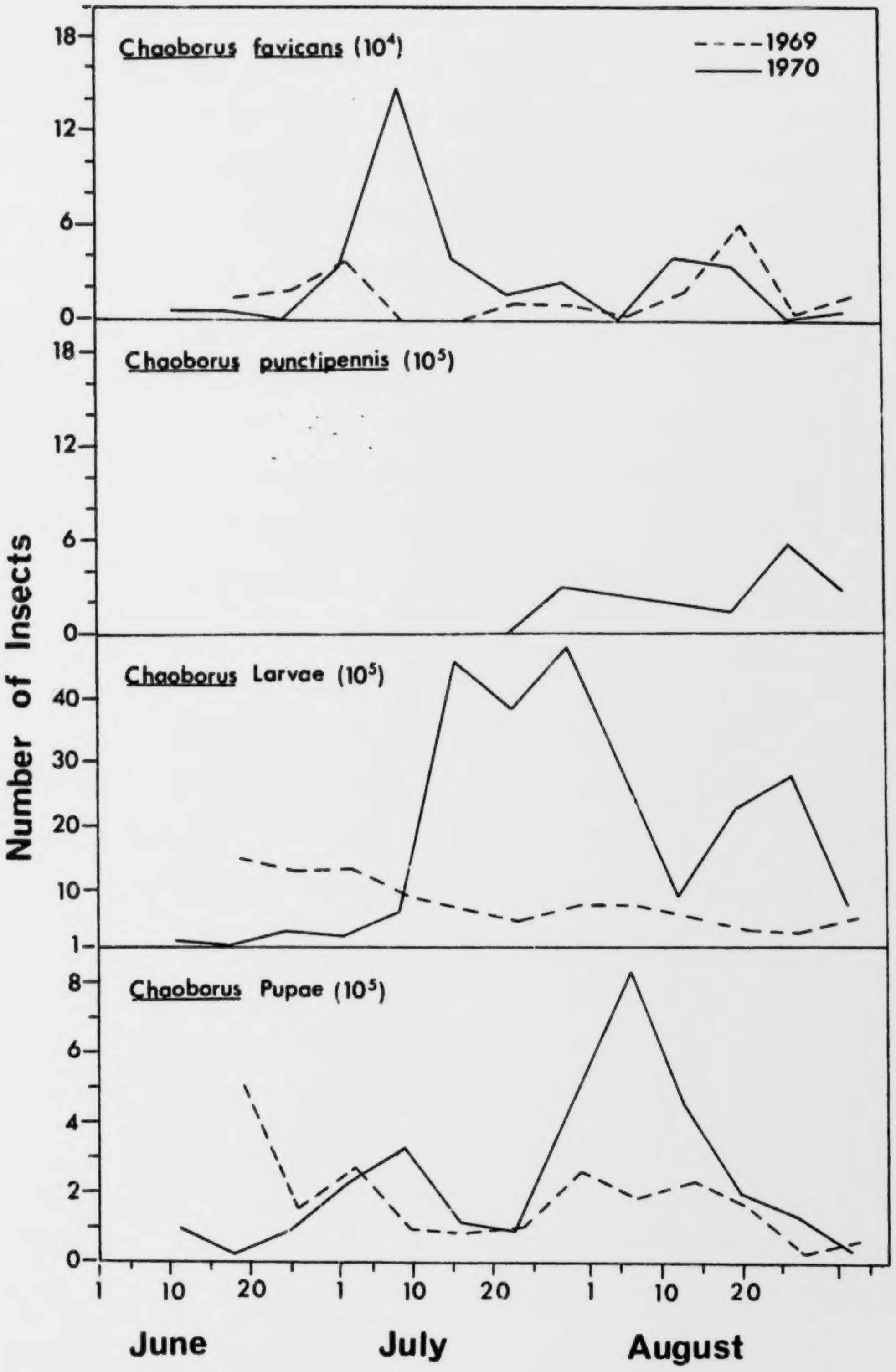

1970
1969
Number of Chaoborus Pupae (10⁵)
0
5
10
15
20
Chaoborus Pupae Biomass (10²gm)
0
10
20
30
40
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 55. Total estimated emergences of Hemlock Lake *Chaoborus flavicans* and *C. punctipennis* during 1969 and 1970. Total estimated larvae and pupae are also shown. All samples are from emergence traps. Aeration occurred continuously between June 14 and September 17, 1970.


Chaoborus favicans (10⁴)
- - - 1969
—— 1970
Chaoborus punctipennis (10⁵)
Chaoborus Larvae (10⁵)
Chaoborus Pupae (10⁵)
Number of Insects
18
12
6
0
40
30
20
10
1
8
4
2
1
10
20
June
July
August

in the deep water, all four instars may remain in the water and not nestle in the mud during the day (Northcote, 1964; Teraguchi and Northcote, 1966). In other lakes, first and second instar are limnetic throughout the day, while the third and fourth instars typically nestle in the profundal sediments during the daylight hours.

Even though estimates of larval abundance in the emergence traps are much lower than dredge estimates, the estimates of relative changes in population sizes are very similar from the two methods (Figures 53 and 55). Estimates of Chaoborus pupal population size are not only much lower from the emergence traps, but relative changes in pupal population size are also dissimilar (Figures 54 and 55). These data indicate that emergence traps and dredge samples provide comparable estimates of relative changes in the larval population, but not the pupal population. The reason for this difference is not obvious.

During 1969, Chaoborus larvae were never collected above 4 m in either the emergence traps or by the dredge (Figures 56, 57 and 58). They were most abundant in the 8 to 12 m depth interval and about 20% were generally present in the 16 to 18.6 m interval. Pupae were present in all depths during 1969, but were generally most abundant between 4 and 12 m (Figures 56 and 58). C. flavicans only emerged from the 0-4 m interval during 1969 (Figure 56).

Chaoborus depth distributions changed greatly following aeration. Larvae concentrations in the 4 to 8 m interval

Figure 56. Depth distribution of *Chaoborus* during the summers 1969 and 1970. All samples were collected by emergence insect traps. A= *Chaoborus flavicans* emergent adults, B= *C. punctipennis* emergent adults, C= *Chaoborus* larvae, D= *Chaoborus* pupae. White areas during emergence periods represent no observed specimens. Aeration occurred continuously between June 14 and September 7, 1970.

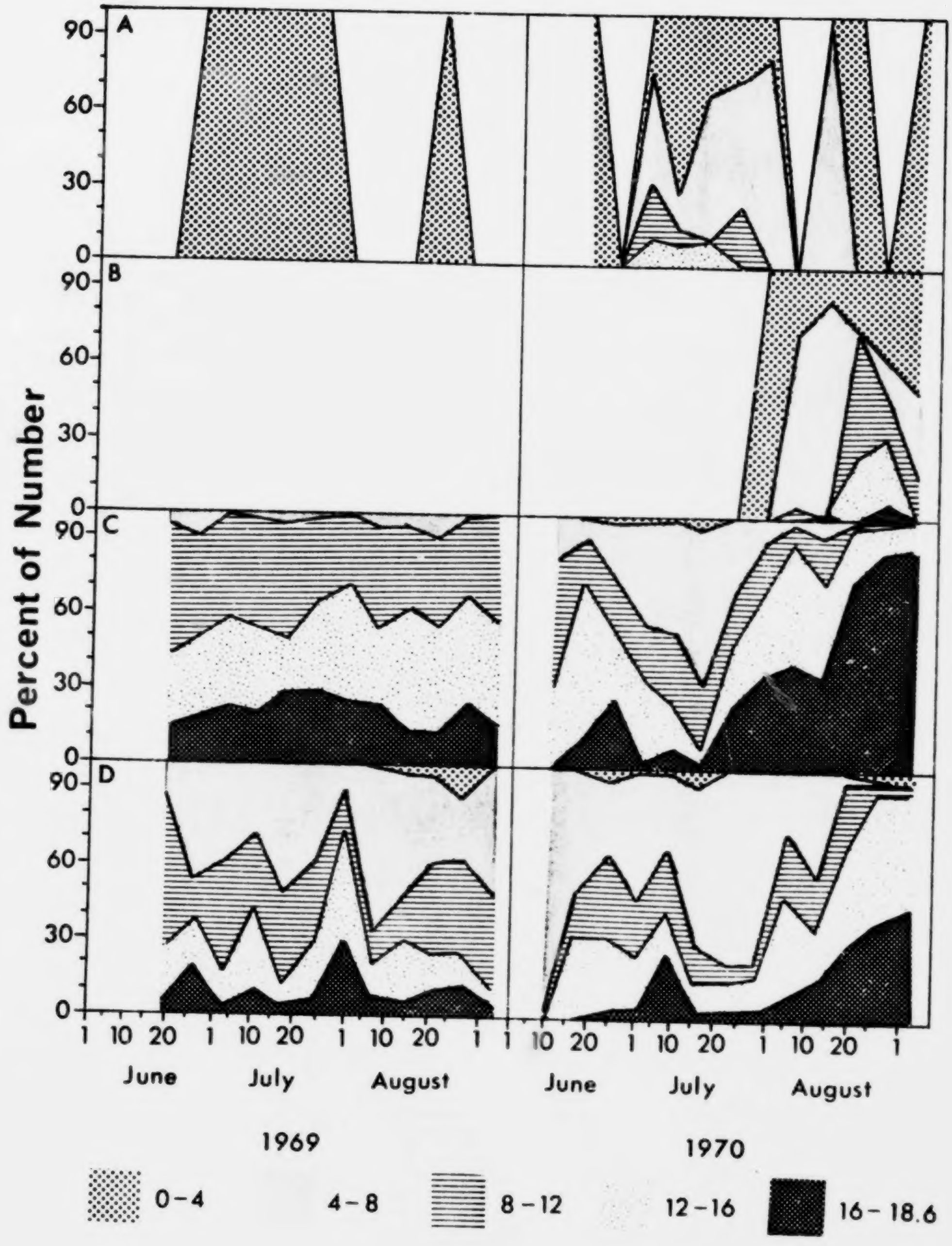

A
B
C
D
90
60
30
0
Percent of Number
1
10
20
June
July
August
1969
1970
0 – 4
4 – 8
8 – 12
12 – 16
16 – 18.6

Figure 57. Hemlock Lake Chaoborus larvae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

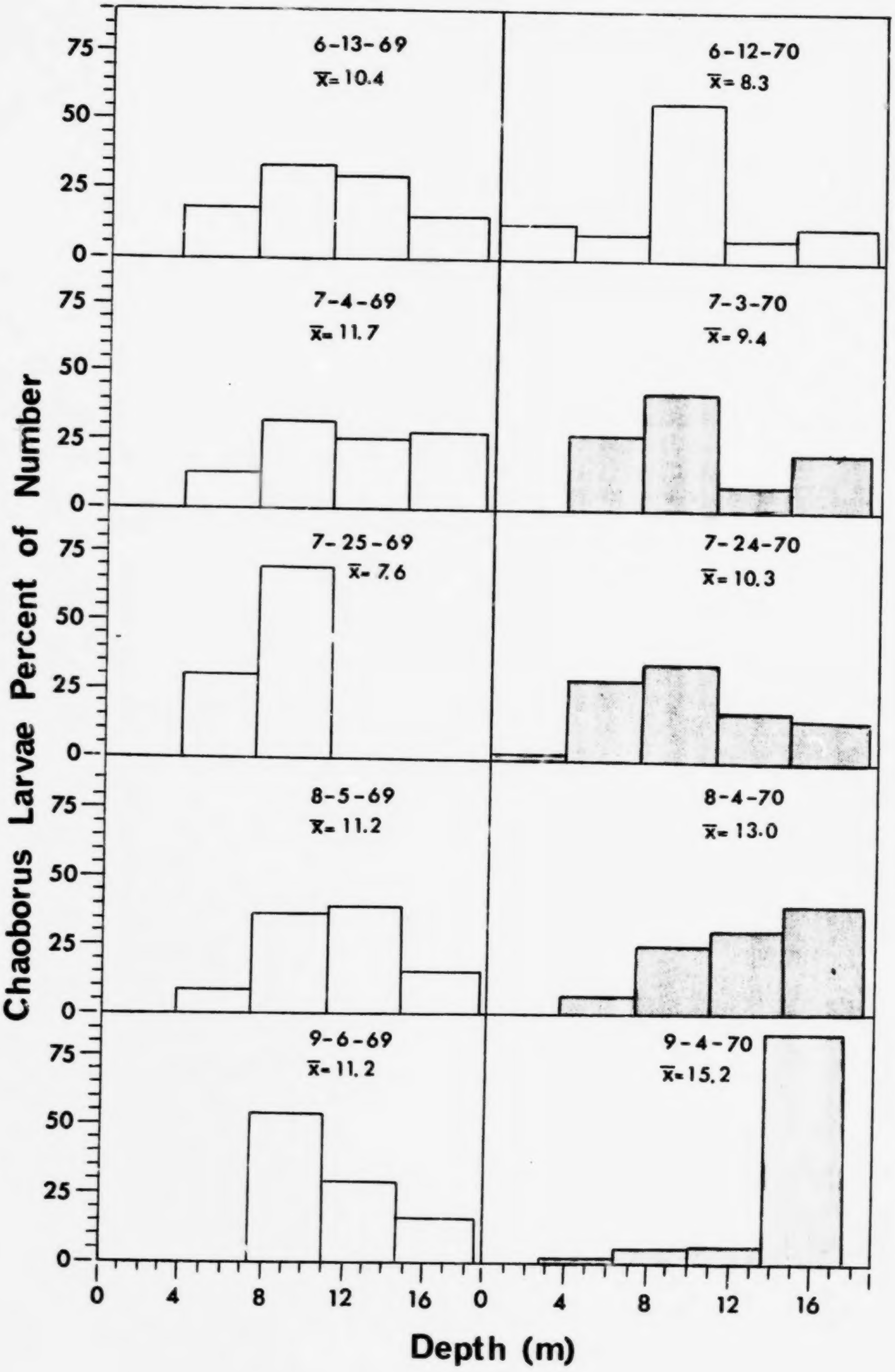
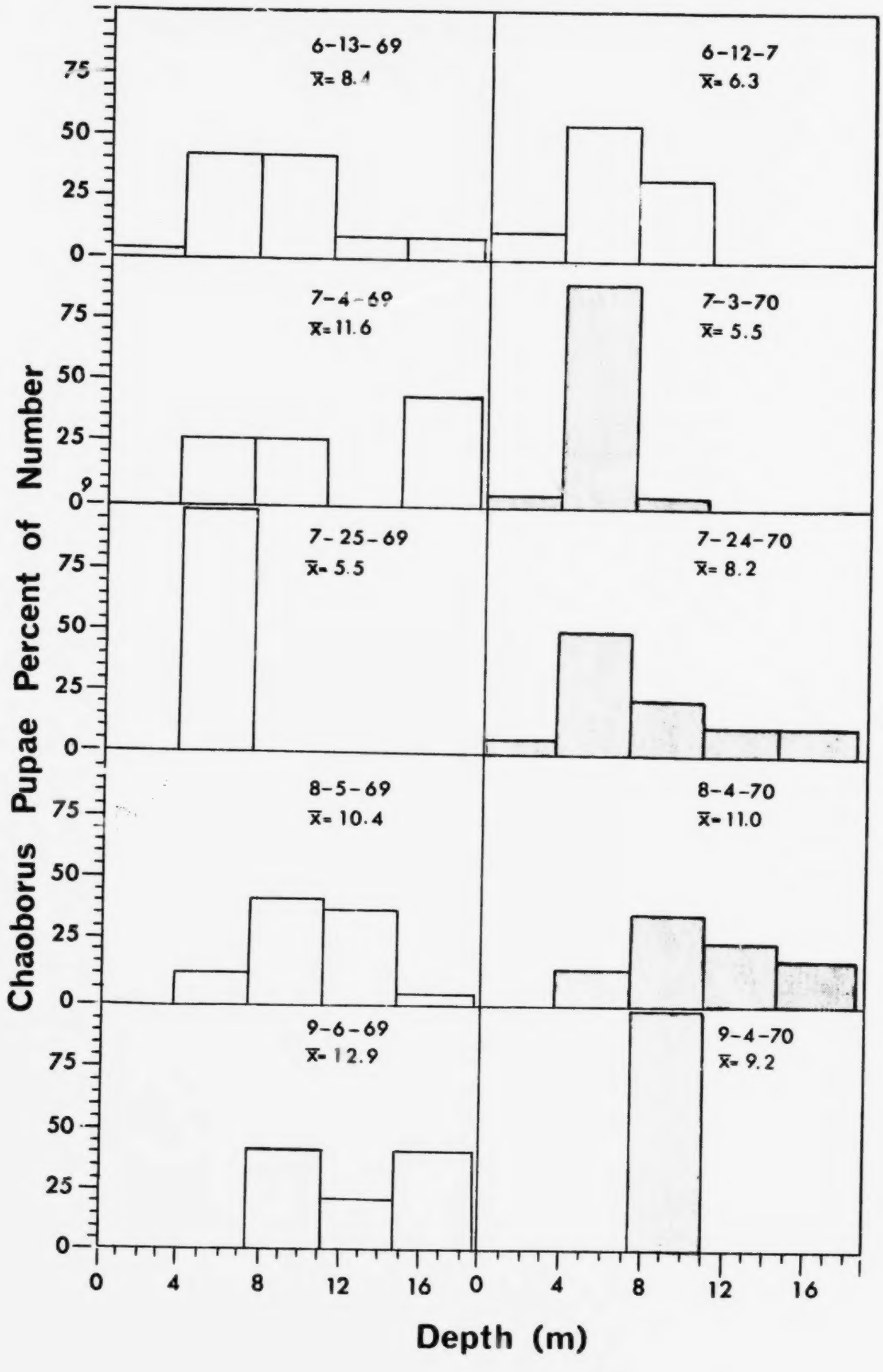

6-13-69
x̄= 10.4
6-12-70
x̄= 8.3
7-4-69
x̄= 11.7
7-3-70
x̄= 9.4
7-25-69
x̄= 7.6
7-24-70
x̄= 10.3
8-5-69
x̄= 11.2
8-4-70
x̄= 13.0
9-6-69
x̄= 11.2
9-4-70
x̄= 15.2
0
25
50
75
0
4
8
12
16
Chaoborus Larvae Percent of Number
Depth (m)

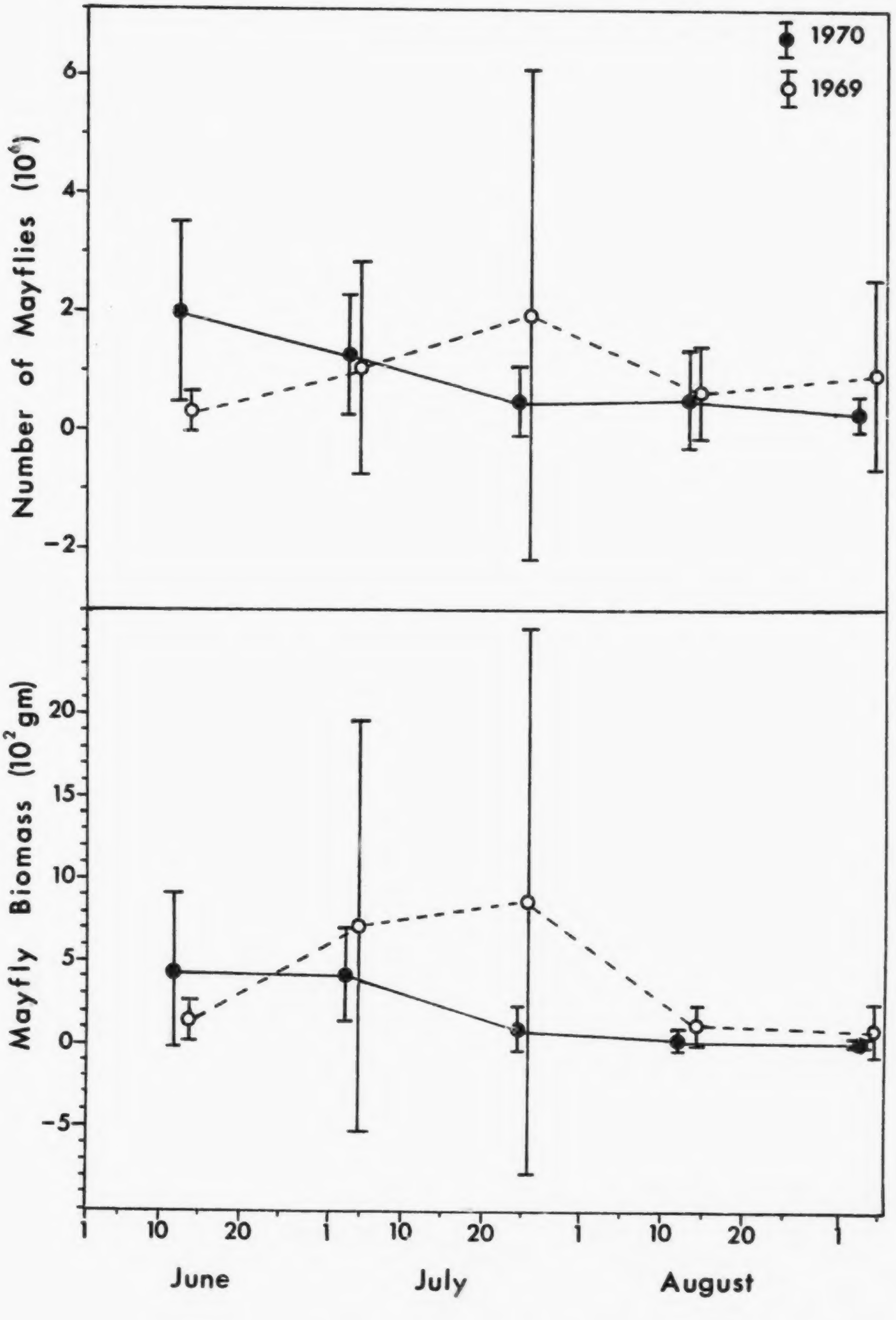
Figure 58. Hemlock Lake Chaoborus pupae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.


6-13-69
x̄= 8.4
6-12-7
x̄= 6.3
7-4-69
x̄=11.6
7-3-70
x̄= 5.5
7-25-69
x̄= 5.5
7-24-70
x̄= 8.2
8-5-69
x̄= 10.4
8-4-70
x̄= 11.0
9-6-69
x̄= 12.9
9-4-70
x̄= 9.2
Chaoborus Pupae Percent of Number
0
25
50
75
9
0
4
8
12
16
Depth (m)

increased steadily until about July 20, 1970 at which time about 60% were collected from this interval. About this same time, larval numbers reached a peak. Thereafter larval numbers declined and pupal numbers increased and C. punctipennis emerged in large numbers. There was also a sharp reduction in number of larvae in the 4 to 8 m interval and a large increase in larvae in the 16 to 18.6 interval. Pupal depth distributions in the emergence traps were similar to larval distributions, but dredge sample distributions are spurious.

Ephemeroptera (mayflies) constituted less than two percent of the macro benthos total weight each year, and less than five percent of the numbers (Table 5; Figure 42). T. Wilson Britt (Ohio State University) identified at least three species of mayflies from Hemlock Lake based on nymphs and emergent adults: Caenis simulans McDunnough (most abundant), Stenonema tripunctatum (Banks) and Callibaetis (least abundant). Mayfly standing crops were about the same each year. Estimates of total numbers in the lake ranged between zero and $2x10^6$ individuals, and estimates of total biomass ranged between zero and 900 grams (Figure 59). One hundred fifteen individuals were collected by the dredge during 1969, and 110 individuals during 1970 (Table 5). Even though standing crops were essentially the same each year, more mayflies emerged during 1970 than during 1969. Peak emergence was over $8x10^5$/week during August 1970, compared to $5x10^5$/week during June 1969. This greater emergence rate

Figure 59. Total estimated Mayfly (Ephemeroptera) number and wet weight in Hemlock Lake during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred continuously between June 14 and September 7, 1970. Totals from dredge samples only.


1970
1969
Number of Mayflies (10^6)
6
4
2
0
−2
Mayfly Biomass (10^2gm)
20
15
10
5
0
−5
1
10
20
1
10
20
1
10
20
1
June
July
August

may reflect increased rates of production not obvious from estimates of standing crop. An interesting feature of mayfly emergence is the similarity of peak emergences each year. Both years peak emergences occurred about July 1st and August 20th. Maximum emergences differed by about 15 days between the two years. These emergence patterns may be caused by different species emerging at different times, but this was not evaluated.

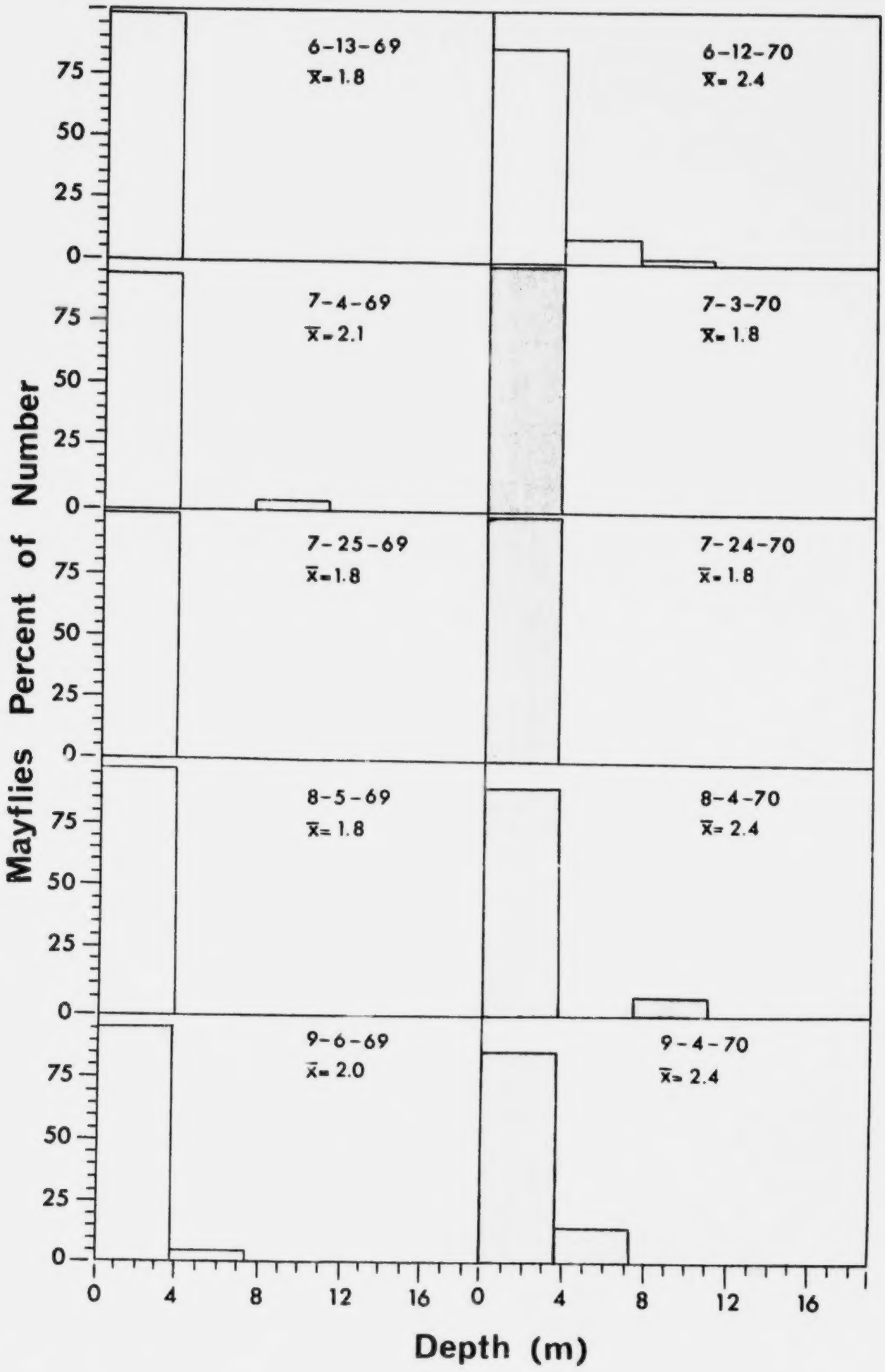
Mayflies were always most abundant between 0 and 4 m depth. Over 85% were always found in this interval (Figure 60). A few individuals were occasionally collected below 8 meters, but never below 11 meters. This distribution persisted both years. Emergence during 1969 was mostly between 4 and 8 m (Figure 51). About 20% of the total emergence 1969 occurred between 0 and 4 m. During 1970, all mayflies emerged from less than 4 m.

One Heleidae was identified by J. A. Downes (Canada Dept. of Agriculture). It belonged to the tribe Stenoxenin; and was probably Jenkenshelea magnipennis (Johannsen). Heleids were not common in the emergents, but comprised about 2% of the biomass standing crop and about 3% of the numeric standing crop.

T. Wayne Porter (Michigan State University) identified only one species of Amphida as Hyalella azteca. Only three amphipods were collected each year.

Jarl K. Hiltonen (United States Bureau of Commercial Fisheries) identified three species of Oligochaeta from

Figure 60. Hemlock Lake Mayfly (Ephemeroptera) depth distribution as percent of number during each each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.


6-13-69
x̄= 1.8
6-12-70
x̄= 2.4
7-4-69
x̄= 2.1
7-3-70
x̄= 1.8
7-25-69
x̄= 1.8
7-24-70
x̄= 1.8
8-5-69
x̄= 1.8
8-4-70
x̄= 2.4
9-6-69
x̄= 2.0
9-4-70
x̄= 2.4
Mayflies Percent of Number
0
25
50
75
Depth (m)
0
4
8
12
16

Hemlock: *Tubifex tubifex*, *Limnodrilus hoffmeisteri* and *Ilyodrilus templetoni*. *L. hoffmeisteri* was most abundant and *T. tubifex* least abundant. Only 4 oligochaetes were collected during 1969, but 267 were collected during 1970. Oligochaetes were found at all depths. They were more abundant at intermediate depths, but no persistent pattern was obvious.

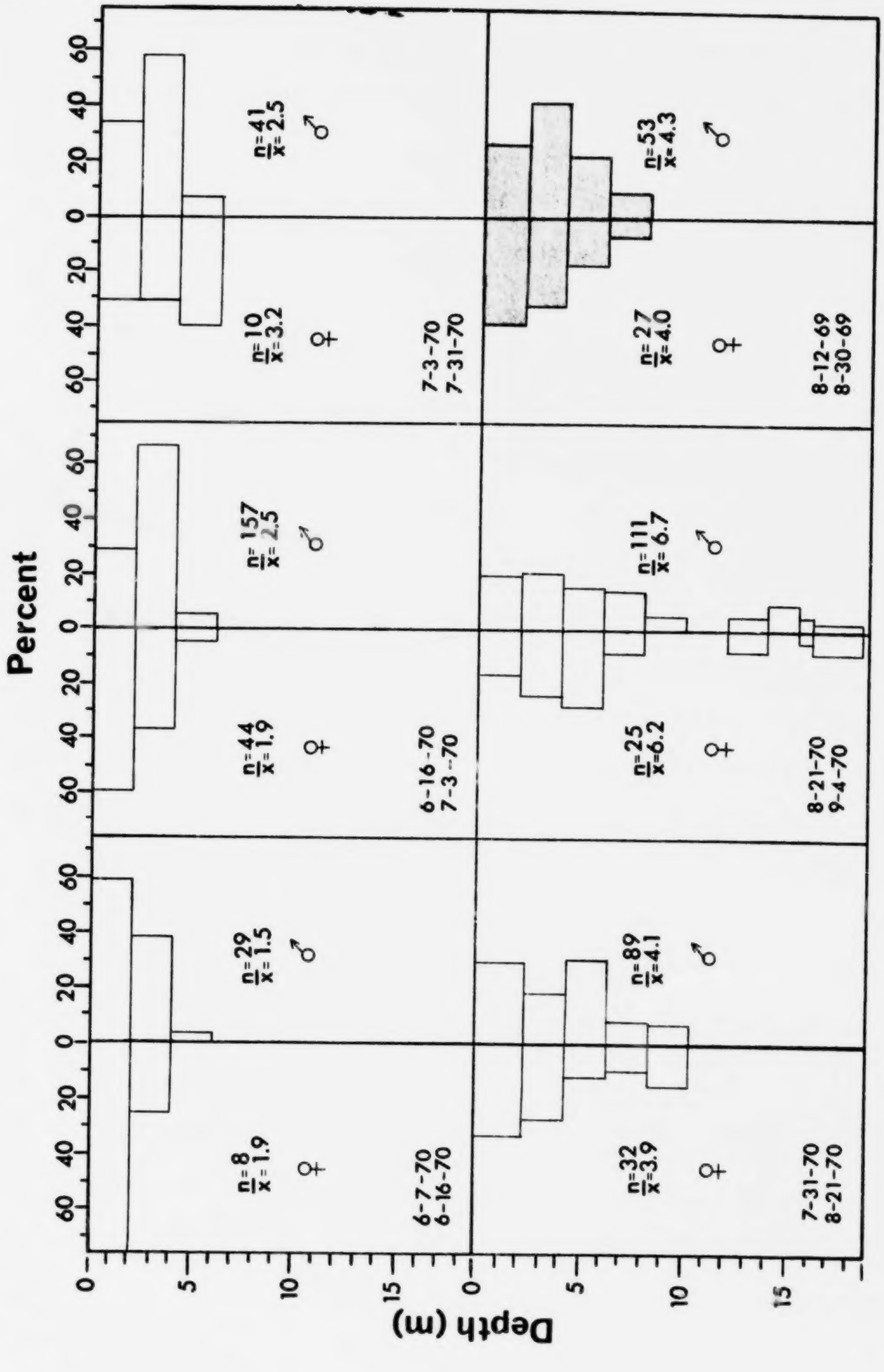
One species of Damselfly (Zygoptera) *Enallaqma*, and two species of Dragonflies (Anisoptera), *Gomphus spicatus* Hagan and *Ladona julia* (Uhler) were identified by Leonora K. Gloyd (University of Michigan). Anisoptera comprised over 35% of the biomass standing crop each year, but less than 2% of the total numbers. Odonata were always most abundant between 0 and 4 m. Naiads were frequently collected in the emergence traps, but adults never emerged in the traps. A very large emergence of *G. spicatus* occurred June 1, 1970. No estimate of its magnitude was made, nor were emergences observed at any other time.

Trichoptera, Tabaniids and leeches were not identified to lesser taxonomic categories because of their small contribution and difficulties in identification.

Crayfish

Crayfish were collected from Hemlock Lake during 1969 only from August 12th through August 30th. During this period, they were found between 0 m and 8 m (Figure 61).

Figure 61. Hemlock crayfish depth distributions during the summers 1969 and 1970. Total numbers during each sample period and their average depths are shown. The shaded area represents the 1969 distributions. Aeration occurred continuously between June 14 and September 7, 1970.


Percent
60
40
20
0
20
40
60
Depth (m)
0
5
10
15
n=8
x̄=1.9
♀
n=29
x̄=1.5
♂
6-7-70
6-16-70
n=44
x̄=1.9
♀
n=157
x̄=2.5
♂
6-16-70
7-3-70
n=10
x̄=3.2
♀
n=41
x̄=2.5
♂
7-3-70
7-31-70
n=32
x̄=3.9
♀
n=89
x̄=4.1
♂
7-31-70
8-21-70
n=25
x̄=6.2
♀
n=111
x̄=6.7
♂
8-21-70
9-4-70
n=27
x̄=4.0
♀
n=53
x̄=4.3
♂
8-12-69
8-30-69

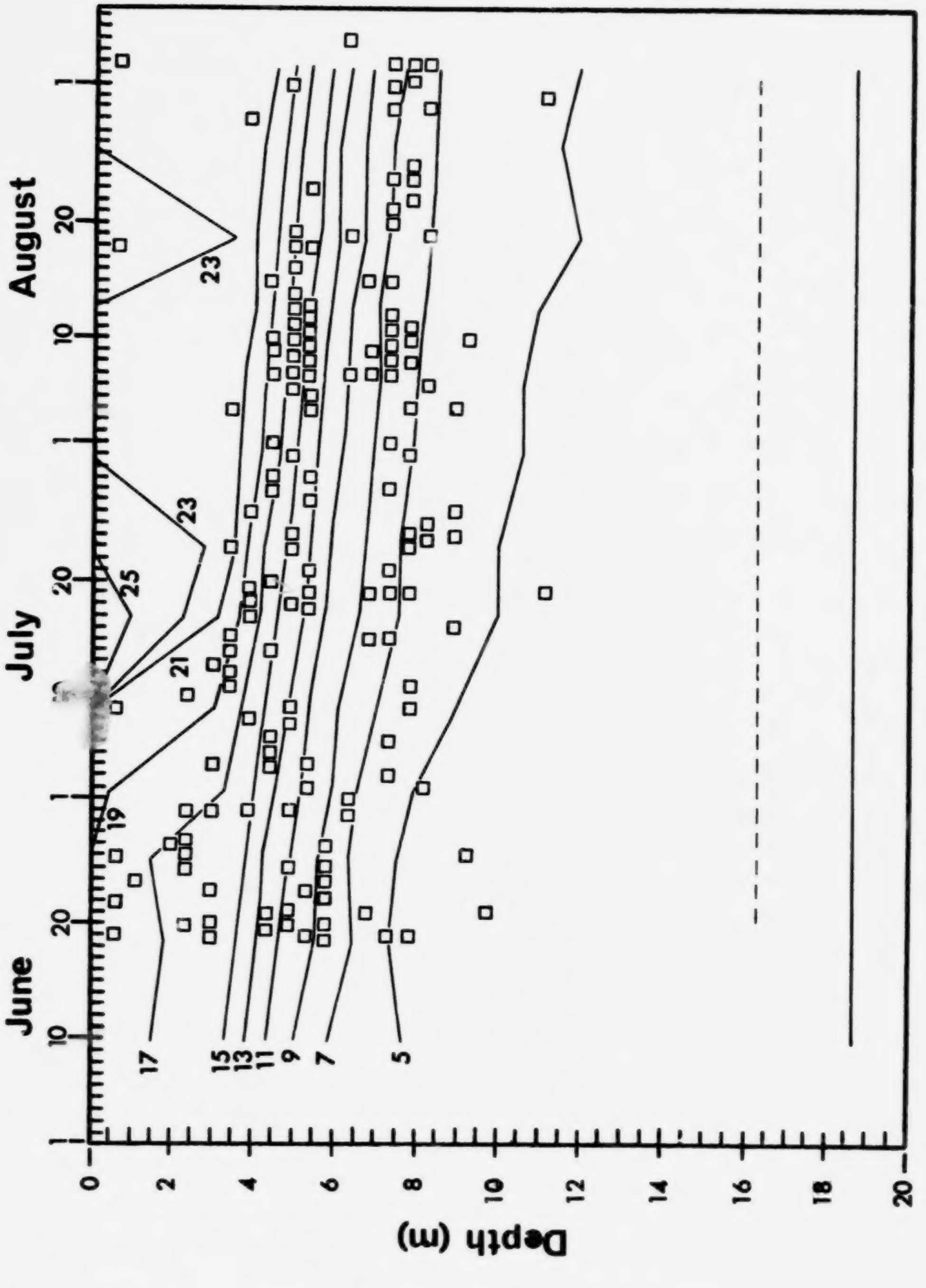
Oxygen and temperature at 8 m were greater than 5 mg/l, and about 8°C. Oxygen was not limiting, but temperature is colder than normal for sustained activity of crayfish (Momot, 1967). Females average depth was 4.0 m, and males had a 4.3 m average. Their sex ratio was 1:2 in favor of the males.

Before aeration began during 1970, the crayfish were confined to 6 m depth or less. The females had an average depth of 1.9 m and the males 1.5 m. Oxygen and temperature at 6 m were 6 mg/l and 7°C respectively. Continuous aeration began June 14, 1970 and continued throughout the summer. After one week of aeration, there was always more than 5 mg/l oxygen in all parts of the lake. The hypolimnetic temperature increased more than 2°C/week. Concurrent with the continuous aeration, the average crayfish depth increased gradually. By the end of the summer, crayfish were found at all depths. The depth distribution for males and females are similar all summer. During August 12th to September 4th females had an average depth of 6.2 m and males 6.7 m. The female to male sex ratio during 1970 was 1:3.6.

Rainbow Trout

Rainbow trout ranged between the surface and 10 meters during June and early July, 1969 (Figure 62). Their lower depth range was undoubtedly defined by the anoxic condition of the deep water. Those fish captured below 7 meters were

Figure 62. Hemlock Lake rainbow trout depth distribution during 1969. These fish were stocked during June 1969 and marked with a right-abdominal fin clip. Each square represents one fish.


Depth (m)
0
2
4
6
8
10
12
14
16
18
20
June
July
August
10
20
1
10
20
1
10
20
1
17
15
13
11
9
7
5
19
21
25
23
23

always dead and moribund. During late July and August 1969, the trout generally ranged between the 7°C and 21°C isotherms. Their lower range was related to the anoxia, but their upper extent appeared limited by warm water.

Before June 14, 1970, the 1969 stocked rainbow trout were again limited to shallow depths. They ranged from the surface to 6 meters (Figure 63). Their lower depth range is again related to anoxia. Continuous artificial hypolimnion aeration began June 14 and continued through September 7, 1970. The trout gradually extended their depth distribution after June 14 and eventually distributed throughout the lake by July 4, 1970. The remainder of the summer 1970, they were found at all depths, with an apparent preference for the bottom during late July and early August.

The rainbow trout held in cages during 1970 distributed throughout the lake when released (Figures 64, 65, 66 and 67). They were most abundant in the 2 to 6 meter zone soon after release (between 10°C and 17°C isotherms), but their range extended from the surface to the bottom. A slight concentration also initially existed at 12 to 15 meters. This general pattern existed for all four lots and indicates that acclimatization did not greatly affect their distribution. Their concentration at 2 to 6 meters persisted for several weeks; thereafter their distribution was more uniform. Throughout the summer they avoided water 21°C or warmer. This same avoidance was also apparent both years with the 1969 stocked trout.

Figure 63. 1970 depth distribution of Hemlock Lake rainbow trout stocked during June 1969. Each circle represents one fish. These fish were marked with a right-pelvic fin chip. Aeration occurred continuously between June 14th and September 7th.

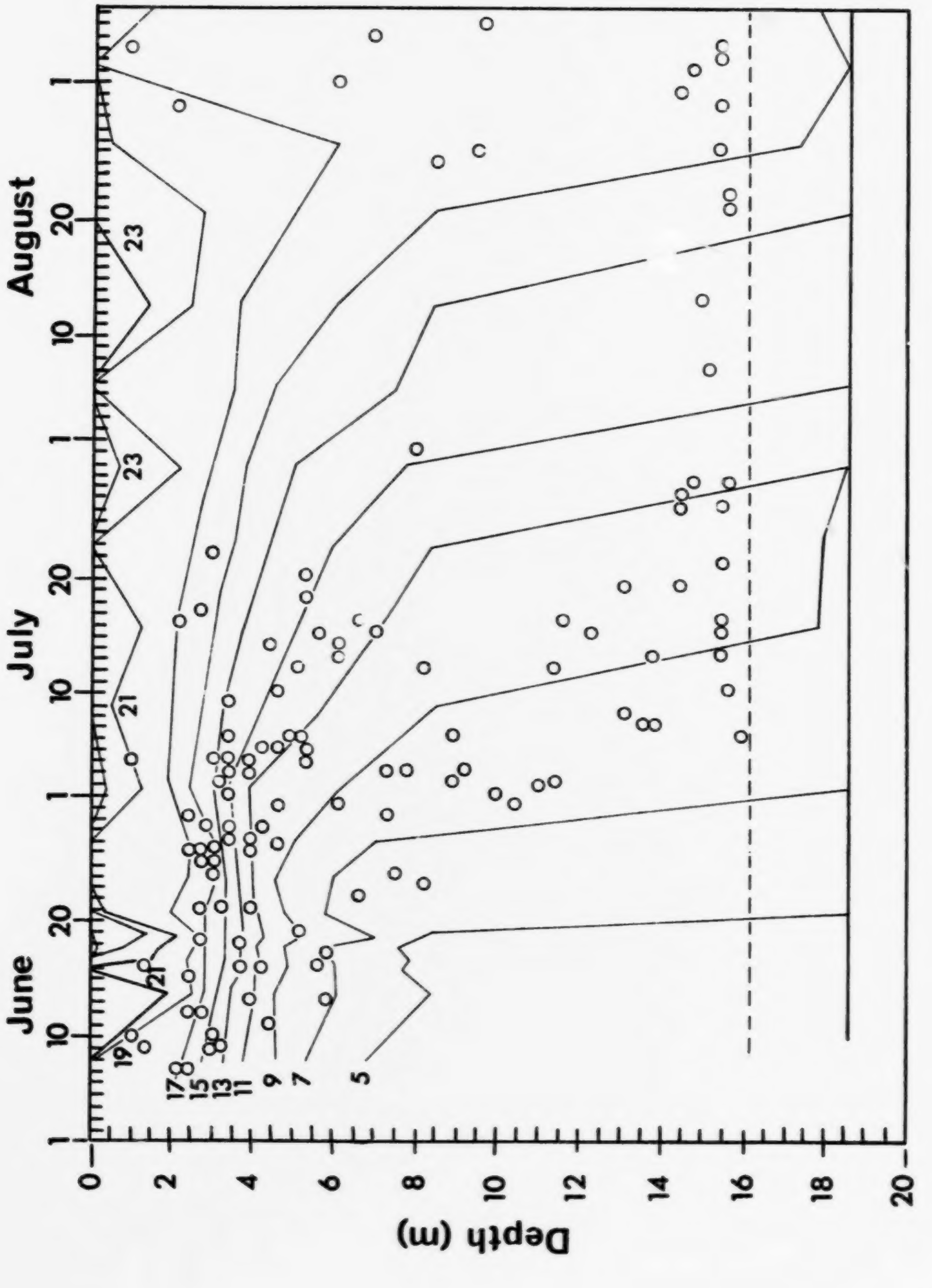

Depth (m)
0
2
4
6
8
10
12
14
16
18
20
June
July
August
1
10
20
1
10
20
1
10
20
1
5
7
9
11
13
15
17
19
21
21
23
23

Figure 64. 1970 Hemlock Lake depth distribution of right-pectoral clipped rainbow trout stocked during June 1970. These fish were held in the 3 m covered cage which received 12 m water for one week before their release. Each circle represents one fish. Aeration occurred continuously between June 14 and September 7, 1970.

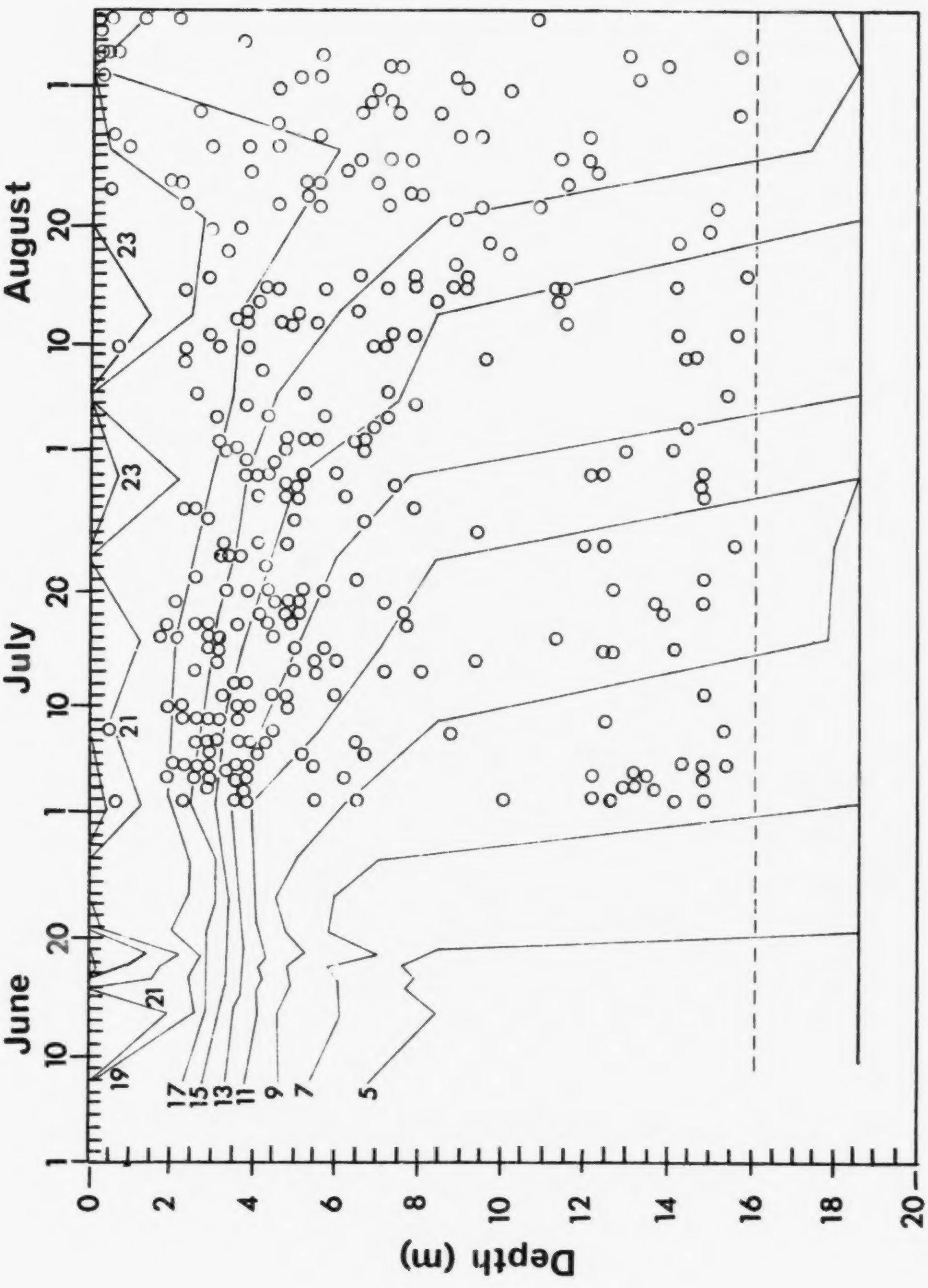

Depth (m)
0
2
4
6
8
10
12
14
16
18
20
June
July
August
1
10
20
1
10
20
1
10
20
1
19
17
15
13
11
9
7
5
21
21
23
23

Figure 65. 1970 Hemlock Lake depth distribution of left-pectoral clipped rainbow trout stocked during June 1970. These fish were held in the 12 m covered cage which received 3 m water for one week before their release. Each circle represents one fish. Aeration occurred continuously between June 14 and September 7, 1970.

205

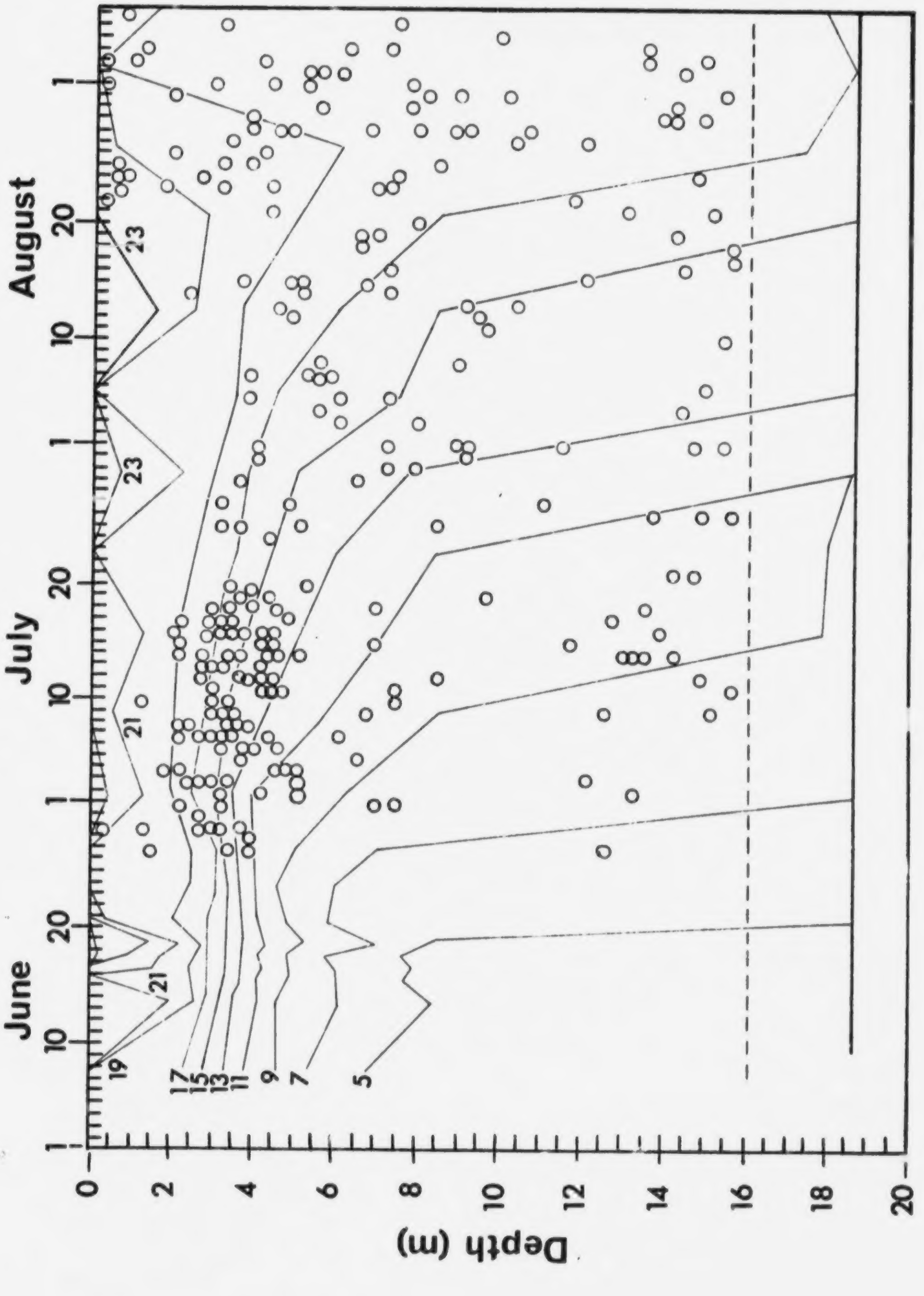

June
July
August
1
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
5
7
9
11
13
15
17
19
21
21
23
23

Figure 66. 1970 Hemlock Lake depth distribution of left pelvic clipped rainbow trout stocked during June 1970. These fish were held in a screened cage at 12 m for one week before their release. Each circle represents one fish. Aeration occurred continuously between June 14 and September 7, 1970.

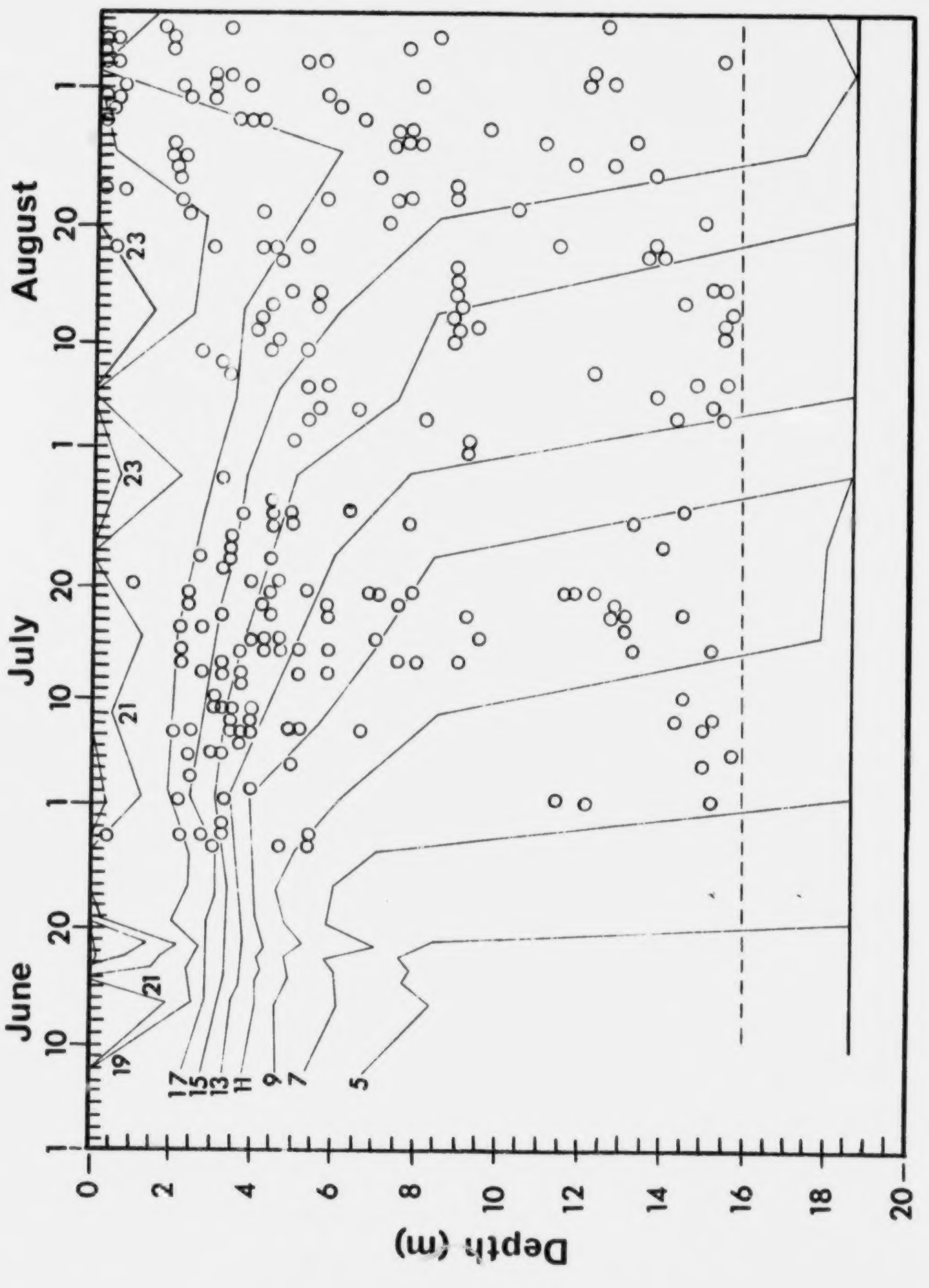
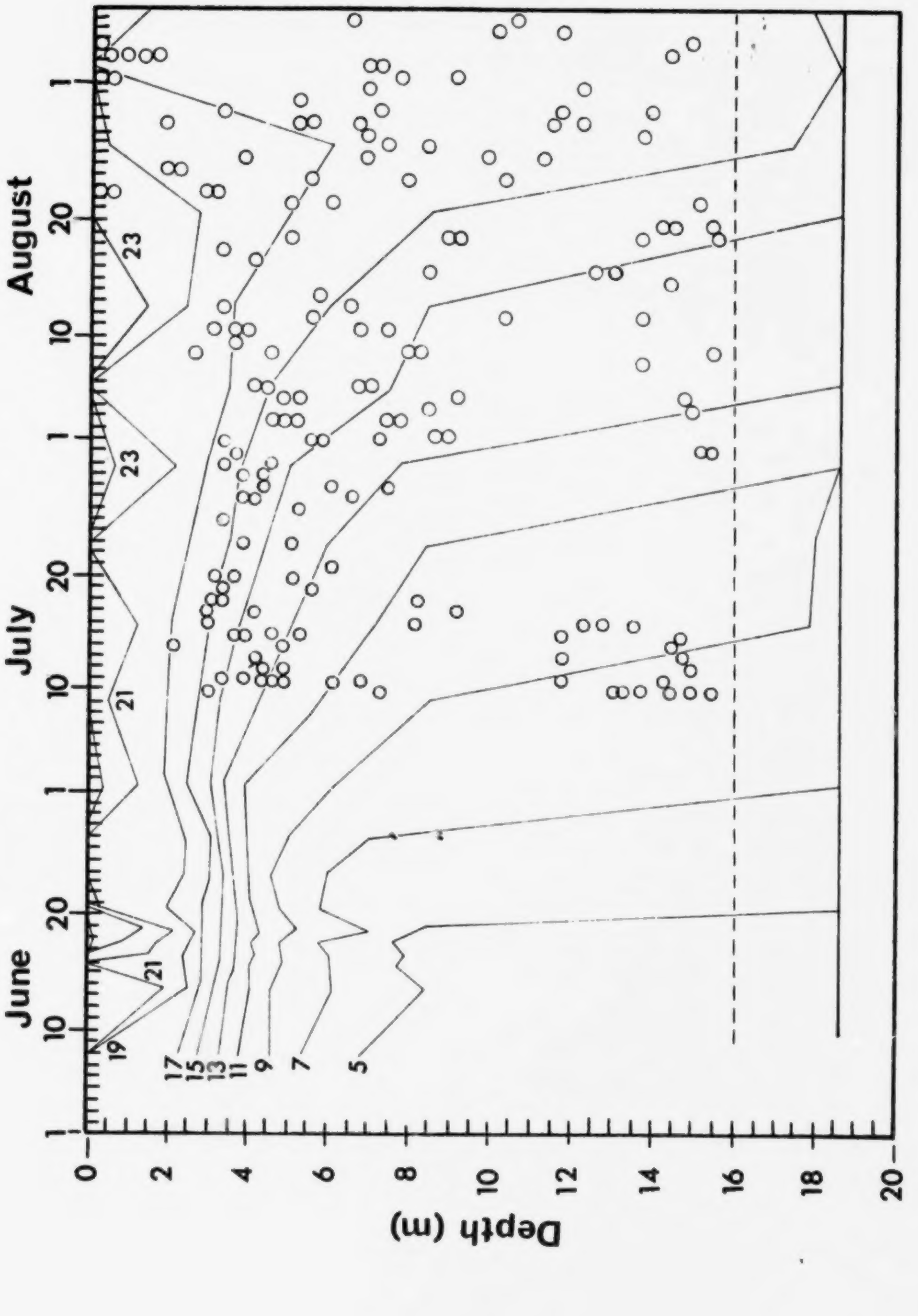

June
July
August
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
19
21
21
23
23
17
15
13
11
9
7
5

Figure 67. 1970 Hemlock Lake depth distribution of anal-clipped rainbow trout stocked during June 1970. These fish were held at 3 m in a screened cage for one week, and then at 12 m in a screened cage for another week before their release. Each circle represents one fish. Aeration occurred continuously between June 14 and September 7, 1970.


June
July
August
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
19
21
21
23
23
17
15
13
11
9
7
5

Rainbow trout grew rapidly in Hemlock Lake both years. Fish less than 200 mm were seldom caught in the gill nets. Although the 1969 stocked fish averaged only 188 mm and the 1970 about 200 mm, many of the smaller fish grew sufficiently during the summers to become vulnerable to the nets. RBT growth rates will not be presented in this thesis.

DISCUSSION AND CONCLUSION

Physical-Chemical Parameters

A lake's oxygen and temperature regimes are very useful indicative parameters. Yearly extremes, and the distribution of oxygen and temperature at any given time reveal much about a lake. Indeed, the kind of life and its spatial and temporal distribution is usually determined in part by the oxygen and temperature regimes. Normally, aerobic biota were excluded from Hemlock's profundal zone by anoxia. Continuous anoxia existed in the monimolimnion. Oxygen was typically depleted in the hypolimnion below 12 meters. This combination of anoxia and cold water undoubtedly contributed to the accumulation of organic debris within the lake, and its enriched condition.

Artificial hypolimnetic aeration greatly altered Hemlock Lake's limnology in general, and its oxygen and temperature regimes in particular. Although the lake gradually destratified during 1970, a well-defined meltalimnion existed most of the summer. As a result of aeration, the monimolimnion was eliminated by mixing with the hypolimnion, and oxygen concentrations were greatly increased throughout the hypolimnion. Hypolimnetic oxygen values often exceeded surface values. This hypolimnetic super saturation relative to the surface was possible due to hypolimnetic low water temperatures and greater hydrostatic pressures.

Based on hypolimnetic oxygen concentration, Hemlock lake was eutrophic prior to aeration, but "oligotrophic" after aeration began. Oxygen values increased from zero before to over 11 mg/l after aeration. This alteration greatly affects the chemical and life processes within the lake. Before aeration, the hypolimnetic waters and profundal sediments were characterized by anaerobic decomposers. These forms are metabolically less efficient than aerobic forms. As evidenced by the highly organic nature of the profundal sediments, these decomposers could not break down the input of organic detritus. The profundal sediments were gelatinous and adhesive before aeration. After aeration began, these sediments readily fell apart when handled. I would attribute this change in character to decomposer changes from anaerobic types to aerobic, and invasion of the profundal zone by macrozoobenthos. The latter include midge larvae and oligochaetes. These zoobenthos accelerate the aeration of the sediments by burrowing and circulating aerated water through their burrows.

Increased hypolimnetic temperatures during aeration must have also affected chemical reaction rates and the growth of microorganisms and zoobenthos. By September 1970, aeration increased hypolimnetic temperature more than

$12^\circ C$ above its usual level. Chemical reactions and metabolic processes generally double with every $10^\circ C$ temperature increase.

Increased hypolimnetic temperature was partly caused by heat conductance through the aeration tower. As the water flowed through the tower and back into the hypolimnion, it absorbed heat through the metal walls of the outer tube (Figure 21). This heating occurred over that region of the outer pipe where the outside water temperatures were greater than the inside temperature. This heating also occurred through the pipe above the lake's surface where the inside water was elevated due to the rising air. During most of the summer this heating through the pipe occurred between 8 meters depth and 0.5 meters above the lake's surface. This heating can and should be virtually eliminated in future designs by insulating the outer pipe. Polyeurothane foam sprayed on the sides of the outer pipe would provide such insulation and also contribute to the tower's buoyancy. This heating should be eliminated if cold aerated water is desirable. If warm aerated water is desired, then an artificial destratification system employing the free release of air is more desirable, since such a system is much more efficient than the one used.

The compressed air temperature is not important as a factor affecting the water temperature. This is true because of low mass and specific heat of the air relative to that of the water, even though the air temperature may exceed $100^\circ C$.

Based on my conservative calculations, the compressed air did not raise the hypolimnetic temperature more than 0.5°C during the entire summer of continuous aeration.

The slightly lower epilimnetic water temperatures, and the altered metalimnion profile, were caused mainly by hypolimnetic water mixed with epilimnetic and metalimnetic waters. This mixing was caused by two factors: (1) Leakage of hypolimnetic water through the upper walls of the aerator, and (2) Leakage of air through lower walls of the aerator. The escaped hypolimnetic water mixed with epilimnetic and metalimnetic waters to form water of intermediate temperature and density. This water flowed into the metalimnion causing it to increase in volume. Air escaping from the lower section of the tower caused hypolimnetic water to upwell around the tower and mix with surface and metalimnion water. This mixed water also flowed into the metalimnion and increased its volume. The metalimnion volume increase should lead to lower epilimnetic water temperatures as normal wind-driven currents erode the metalimnion from above. Higher hypolimnetic temperatures and aerator-driven hypolimnetic currents also erode the metalimnion from below. Heat loss from the surface waters into the tower also contributed to this process, but is probably of less importance. Water and air losses from the tower were caused by faulty design. The riveted plates forming the pipe walls should have been caulked, but were not. Water and air passed through the pipes at the joints. This fault can easily be overcome in future designs by either caulking between the plates, or by using welded pipe which lacks overlapping plates and is watertight.

Schmidt (1915) defines thermal stability in terms of energy required to change a thermally stratified lake to one of equal temperature throughout. A thermally stratified lake has a shallower center of gravity than an isothermal lake. This fact arises from water's specific density properties as a function of temperature. Pure water is at maximum density at 3.94°C and less dense above or below this temperature. The less dense water is near the surface. Thermal stability is zero when a lake is isothermal and reaches maximum value when the lake is well stratified. Stability is therefore a measure of destratification. It is not an absolute measure, since Fast (1968) found it partly a function of water volume. Hemlock's thermal stability was greater during June 1970 than during June 1969 because of warmer surface waters during June 1970. It gradually decreased to near zero during the summer 1970 as the lake gradually destratified. It thereby reflects the gradual converging of maximum-minimum water temperatures during 1970. An opposite trend occurred during 1969 when the stability was near maximum by the end of the summer.

I had expected an increase in average pH and a decrease in average alkalinity following aeration. As carbon dioxide was removed from the hypolimnetic water by the injected air, I expected the following net reaction:

$$Ca^{++} + HCO_3 \rightleftharpoons CaCO_3\downarrow + H_2CO_3 \rightleftharpoons CO_2\uparrow + H_2O$$

This should result in a net decrease in calcium ions in solution, an increased pH and decreased total alkalinity. Average alkalinity was slightly higher after aeration (Figure 36), while average pH was slightly lower (Figure 35). Calcium showed the most variability (Table A-11). It decreased from an average 47.7 mg/l on June 13, 1970 to a 40.8 mg/l average minimum during July 17th. The greatest decreases occurred in the deep water. This suggests that during this period $CaCO_3$ was precipitated within the hypolimnion as the carbon dioxide was driven off. From July 17th to August 15th the average calcium concentration increased greatly to 55.4 mg/l maximum. The greatest increases occurred in shallow water. The lake's gradual destratification in late August may have caused this increase. The free carbon dioxide concentration of shallow waters may have been increased and caused a re-solution of shallow water $CaCO_3$ deposits. Surface CO_2 concentrations were 1.4 mg/l on June 13th, but 5.4 mg-1 on September 2nd, although the average CO_2 concentrations for the lake on these dates were 22.0 mg/l and 5.4 mg/l respectively. The shallow water sediments were much richer in $CaCO_3$ than the profundal sediments (Figure 15).

I had expected greater changes in the dissolved organic matter. The average concentrations varied between 7.04 and

10.46 mg/l. For any given date surface concentrations were similar to bottom concentrations. I anticipated precipitation of DOM as it passed through the aeration tower. H. B. Hynes (personal communication, University of Waterloo), observed such precipitation when DOM from leaf extract was mechanically agitated in a flask. This process should have caused a reduction in DOM within the lake. Concurrently I expected an increase in DOM as the profundal microbiota changed from anaerobic to aerobic forms and accelerated the decomposition of the highly organic profundal sediments. Possibly these two processes did occur to a significant but nearly equal extent and balanced each other's effects. R. G. Wetzel (personal communication, Michigan State University) feels that a more likely explanation is that the DOM fraction is composed mostly of biologically highly refractory organic compounds that are not subject to much change and there was little net input from the sediments. The particulate organic matter varied greatly during the summer. This variation is related to changes in organic production rates. R. G. Wetzel plans to evaluate the effects of aeration on DOM, POM, Ca, K, Na and Mg in much greater detail in a later publication.

We originally planned a more intense evaluation of phosphorus. However, due to the inherent variability and limited resources, this plan was aborted. Barrett (1952) studied the effects of artificial fertilization on the phosphorus contents of these lakes in greater detail than we intended. His results were often incongruous with expected results. To be sure, phosphorus is an important nutrient and often the limiting factor, or is associated with the limiting factor of primary production. However, other nutrients such as Mo, Co, Zn, or Mn can also be limiting (Goldman, 1962). Many other conditions or substances can also affect production. As Rigler (1964) quite skillfully points out, we do not know very much about the cycling of phosphorus with a lake ecosystem. The forms phosphorus takes, its concentrations with ecosystem "compartments" and especially the rate functions between compartments are unknown and not easily measured. The best we could hope for in our study was to determine the changes in the vertical concentrations of total and dissolved phosphorus; but this could readily be inferred from changes in oxygen concentration. With these facts in mind, I decided to discontinue phosphorus determinations after 1969 and concentrate my efforts on evaluating the effects of aeration on production and standing crops of the biota.

Primary Production

Primary production changes are sensitive indications of changes in nutrient availability, as well as many other basic conditions in a lake. Unicellular primary producers respond very rapidly to these changes. They integrate changes in a large number of variables to produce a given response, a feat not fully understood. Responses include changes in species composition as well as production rates. Happenings at the primary producer level are ultimately passed along to higher trophic levels. Although the transmission route is not fully understood, high primary production generally leads to high production at higher trophic levels. High primary production also leads to eutrophy and hypolimnion stagnation, conditions I intended to eliminate by artificial hypolimnion aeration.

Although aeration did eliminate hypolimnion stagnation, it did not reduce primary production during the entire summer. My hypothesis is that if nutrient regeneration due to hypolimnetic anoxia constitutes a significant input to the nutrient cycle, then hypolimnion aeration should reduce this input and lead to reduced nutrient and primary production levels. Unless a net nutrient flow exists from the anoxic hypolimnion to the trophogenic zone, then primary production reductions should not occur until the fall turnover following aeration, and during subsequent periods if high profundal oxygen concentrations are maintained.

Almost immediately following the beginning of artificial aeration during June 1970 an intense plankton bloom developed. I attribute this bloom to leaks in the aeration tower. When aeration began, hypolimnetic water was especially rich in nutrients. Significant quantities of this water leaked through the tower into the epilimnion. These nutrients undoubtedly led to the intense plankton bloom. The bloom subsided to a very low level by the end of July 1970. At that time, the lake was clearer than at any known time, while planktonic primary production and standing crops were less than during 1969. I attribute this decline primarily to nutrient deprivation. Although hypolimnetic water leaked through the tower all summer, I believe many of the nutrients became oxidized and effectively removed from the hypolimnetic water soon after aeration began. The profundal mud surface was oxidized by the artificial aeration. Such a surface has a large capacity to remove phosphorus from the water by sorption (Fitzgerald, 1970). Nutrients such as iron, phosphorus and manganese were probably precipitated directly by the advent of aerobic conditions, higher redox potentials and higher pH.

Another indication that nutrient limitation contributed to the plankton decline during July 1970 is reduced primary production efficiencies. Efficiency is measured as the rate of primary production in mgC/m^3/4 hours per phytoplankton cell. A more appropriate measure of phytoplankton biomass could be used, such as cell volumes or chlorophyll concentrations, but these measures were not available. The observed production rate is actually a measure of the "production potential" and not the true in situ production rate. As will be demonstrated later for Section Four Lake, these two properties can be quite different. The production rate was measured in a constant light-intensity chamber and many of the variable lake influences are thereby eliminated or diminished. In any event, this production rate is a valuable measure of production potential, and the efficiency ratio provides a measure of the ability of each cell to grow and reproduce. High efficiencies imply an adequate environment and vigorous population. Low efficiencies imply nutrient limitation or some other deleterious condition.

We observed a nearly uniform efficiency value of less than 5 $mgC/m^3/4$ hrs/ln cell during most of 1969. This efficiency increased markedly after aeration began, to more than 45 and subsequently declined to less than 5 by late July. The efficiency increase implies more desirable conditions for phytoplankton growth, such as provided by increased nutrient concentrations. Decreased efficiencies could be attributed to the removal of the same factor. It should be noted that maximum efficiencies do not coincide with maximum phytoplankton standing crops during June and July 1970. A number of factors could contribute to this situation, such as: (1) changes in phytoplankton species composition, with different species having different growth potentials and nutrient requirements, (2) change in size of the phytoplankters. Since we have essentially equated all cells in our efficiency parameters, cell size alone could influence the parameter, and (3) zooplankton grazing. Standing crop reduction without a corresponding production efficiency reduction may be due to intensive zooplankton grazing. Nutrient limitation should not produce these effects, but on the contrary cause a corresponding reduction in efficiency. Harvey et al. (1935) have demonstrated that zooplankton can exert a substantial influence on the phytoplankton population. Intense grazing could possibly reduce the plankton population without reducing the production efficiency. Large zooplankton population sizes probably occurred in Hemlock during early and mid-July, coinciding with maximum primary production efficiencies. Brooks and Dodson (1965) suggest that the kind and quantity of zooplankton can effect the kind and quantity of phytoplankton. Large standing crops of large zooplankton should lead to reduced phytoplankton standing crops, whereas large standing crops of small zooplankters should favor large phytoplankton standing crops. Hrbáček et al. (1961) found that dominant small zooplankters favor the abundance of nannoplankton, as well as larger phytoplankters. Small zooplankters presumably cannot harvest small phytoplankton as efficiently as large zooplankters, nor can they handle large phytoplankters. The large zooplankter Daphnia pulex became very abundant in Hemlock during July, and a large increase in the smaller zooplankter Bosmina was also observed. The kind of zooplankton that is present is largely controlled by fish predation. Changes in phytoplankton species composition caused by zooplankton grazing could account in part for the lag in production efficiency relative to standing crop in Hemlock Lake, but probably not the large decrease in efficiency during late July.

The very low phytoplankton production and standing crop values during late July and early August suggest that there could ordinarily be a net movement of nutrient from the hypolimnion during hypolimnetic stagnation. This suggestion is supported by the lower plankton populations during this period of 1970 when the hypolimnion was aerated, than during the same period of 1969 when the hypolimnion was anoxic. There was probably a net movement of nutrients from the limnetic compartments into the littoral and profundal compartments during June and July 1970 (Figure 1). Aerobic hypolimnetic conditions prevented nutrient regeneration from the hypolimnion. Aerobic littoral muds and plant growth prevented regeneration from the littoral zone. These net losses would result in lower phytoplankton production.

Following the 1970 phytoplankton minima, there was a gradual increase in standing crop, production potential and production efficiency during the remainder of the summer. I believe this recovery can also be attributed to changes in nutrient levels, but by a different mechanism than associated with the earlier plankton bloom. I believe there were two main sources for the nutrients that sustained the August bloom: nutrients released from the littoral compartment, and nutrients released from the profundal muds. Hutchinson (1941) found large increases in phosphorus concentrations associated with temperature increases. He concludes, "... that this phosphorus can only have come from the marginal sediments. Such a sudden excess of the element is undoubtedly due to an increased rate of organic decomposition in the shallowest mud and in the organic debris in the weed beds of the lake." (Hutchinson, 1957.) If this is true, then this same mechanism could have resulted in aerobic nutrient regeneration from the profundal sediments. These nutrients would have become available to the limnetic algae from leaks in the tower, but more importantly by the increased thermal destratification that occurred during August 1970. This destratification rate was accelerated as temperature differences diminished between shallow and deep water. Increased oxygen and temperature content of the profundal sediments should have greatly accelerated their decomposition. These sediments are very high in incompletely decomposed organic matter. Before aeration, decomposition was hindered by anaerobiosis and low temperatures. Aeration increased oxygen concentrations from zero to over 10 mg/l, and temperatures from less than 5°C to 19°C. Aerobic bacteria are more efficient decomposers and undoubtedly accelerated decomposition rates. Macrozoobenthos such as Chironomids and oligochaetes undoubtedly accelerated this process by burrowing through the sediments. Increased decomposition rates and water circulation through the sediments may have caused aerobic nutrient regeneration. This process was probably greatest during late summer and probably accounts in large part for the August plankton bloom.

It may seem incongruous to credit nutrient depletion for cessation of the bloom during July, and nutrient regeneration for the August bloom. I am guessing that the nutrient depletion was caused by precipitation and sorption of nutrients by the sediments. A net influx of nutrients to the profundal sediments could have occurred during early summer, before they were greatly heated and before microbial and macrozoobenthic populations were established. A net output from the profundal sediments could have occurred later in the summer due to increased decomposition. The latter hypothesis may be partly supported by the foam production. Foam first became noticeable about August 1, 1970. This coincides with the commencement of the second phytoplankton bloom. Although the composition and source of the foam is unknown, it is probably a dissolved organic substance. It could have been generated by the accelerated decomposition of the profundal sediments. H. B. Hynes (personal communications) observed the precipitation of DOM from leaf litter. This precipitation was promoted by shaking. Particles of larger size were formed by longer periods of agitation. Increased profundal decomposition could have released DOM as well as other nutrients. Our estimates of DOM concentration are too incomplete to shed much light on this hypothesis. Furthermore, complete concentration estimates might not provide the answer since the rates of generation and utilization and the nature of the material is of greater importance.

R. G. Wetzel (personal communications) feels that most of the DOM generated may be utilized very rapidly by the microbes, such that essentially only the refractory fraction remains. Static measures, such as concentration, would therefore not give an accurate picture of its role.

A minimum DOM value of 4.68 mg/l at 15.6 m was observed August 15, 1970. This occurred during a 4 or 5 day cessation in foam production. Foaming began again on August 19th and continued until we stopped aeration. A maximum DOM concentration of 10.89 mg/l was observed September 5th. If foam is formed from DOM produced by decomposition of the profundal sediments, then it also indicates that other nutrients are also being generated by this decomposition. This supports my hypothesis that the second plankton bloom was promoted by nutrient regeneration from the profundal sediments.

If primary production is to be reduced, then it appears essential that nutrient regeneration from the profundal sediments be greatly reduced. Whether this regeneration is by anaerobic decomposition, or by aerobic decomposition, the results could be the same; but it is too early to tell. Continued hypolimnion aeration could lead to a well-oxidized and mineralized "crust" on the profundal sediments. This could occur due to microbial decomposition and continuous oxidation of the sediment surface. Once this crust is formed, aerobic nutrient regeneration might be minimal, or at least less than the former anaerobic nutrient regeneration. Even on a short-term basis, a leakproof aeration tower will greatly reduce the impact of nutrient regeneration. These nutrients may mostly remain in the hypolimnion during the warm summer months and be essentially unavailable for plankton growth until turnover, sometime in the fall.

Periphyton standing crop may be taken as a measure of attached algal net production. This is not strictly true since many kinds of biota are included in this measurement. In most cases, it probably affords a simple measure of attached algal relative production.

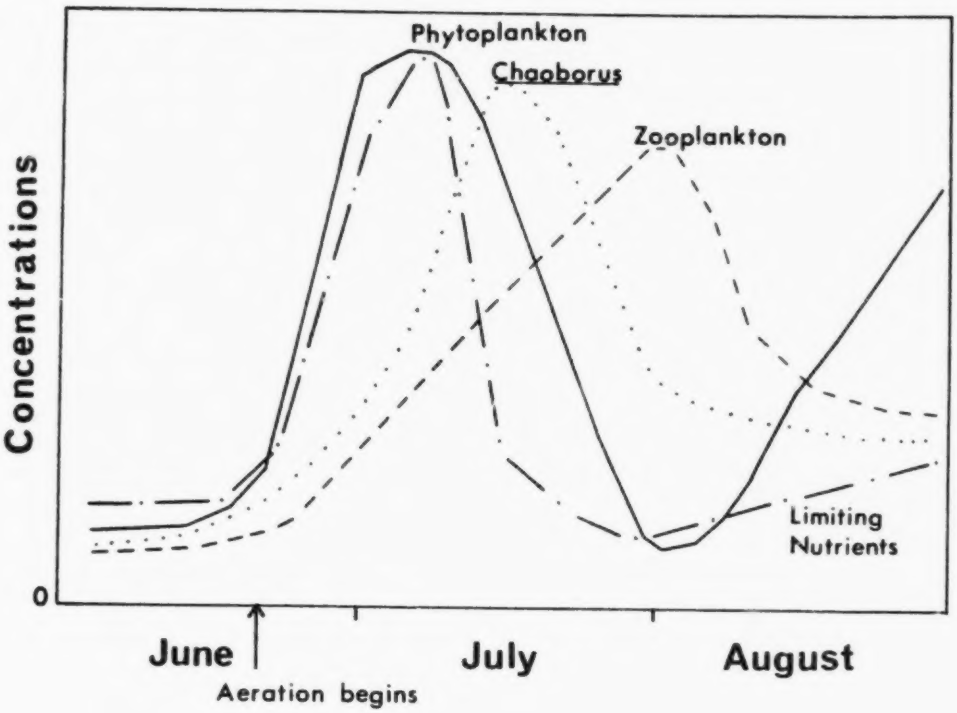
Long-term periphyton accumulations were significantly greater following aeration compared to comparable non-aerated periods. Likewise, short-term accumulations were significantly greater except during late July and early August 1970. During this later period, accumulation rates were similar both years. Even long-term accumulations had a slight slump during late July 1970. These changes in periphyton accumulation rates indicate that both populations were affected by the same variables, the most likely being nutrients. It seems unlikely that herbivore grazing on both kinds of primary producers could cause such similar response patterns. Under some circumstances, increases in phytoplankton production could lead to reductions in periphyton production due to shading or nutrient deprivation. Conversely, periphyton growth could limit phytoplankton by nutrient deprivation, but not by shading. Neither event was apparent in Hemlock Lake. This was probably due in part to the vertical distribution of the periphyton. It was mostly concentrated in the upper few meters and thus not greatly affected by shading due to dense phytoplankton populations. Likewise, both populations seemed to "share" the nutrients and thus responded in a similar manner.

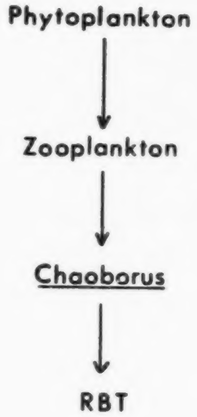
Periphyton never appeared overly abundant on logs or other suitable substrate. Submerged aquatic plants and algal mats were likewise sparse. Tanner (1952) observed similar responses at moderate fertilization rates. He also observed a primary response by the phytoplankton. Ball (1949) and Ball and Tanner (1951) on the other hand observed no more than a moderate increase in plankton production at heavy fertilization levels. Their primary response was by attached forms and floating algal mats. Heavy fertilization led to winterkill conditions, whereas winterkill conditions were approached with moderate fertilization.

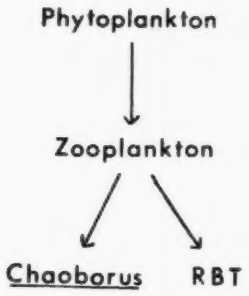
Zooplankton

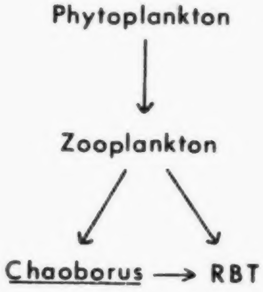
After phytoplankton, the zooplankton appeared to give the greatest response to artificial aeration. *Daphnia pulex*, *Diaphanosoma* and *Bosmina* had especially large increases in total numbers. Unfortunately, we do not have estimates of their seasonal abundance patterns. Figure 68 illustrates the hypothetical changes in limnetic zooplankton, phytoplankton, *Chaoborus* and limiting nutrients during the summer 1970. It also shows the major food chain relationships. *D. pulex's*

Figure 68. Hypothetical changes in Hemlock Lake limiting nutrient, phytoplankton, zooplankton and *Chaoborus* densities during 1970. Aeration began June 14th and continued through September 7th. Major food chain relationships are also shown.


Phytoplankton
Chaoborus
Zooplankton
Limiting Nutrients
Concentrations
0
June
July
August
Aeration begins


Phytoplankton
Zooplankton
Chaoborus
RBT


Phytoplankton
Zooplankton
Chaoborus
RBT


Phytoplankton
Zooplankton
Chaoborus
RBT

abundance seems related to predation by trout, phytoplankton abundance and hypolimnion oxygen depletion. *D. pulex* was scarce before aeration began. I attribute this scarcity to predation by rainbow trout. Before aeration, *D. pulex* were mostly limited to depths above 9 meters by hypolimnetic oxygen depletion. In this zone they were especially vulnerable. After aeration began, they inhabited the dimly lit depths of the lake. This sanctury, in addition to increased primary production, allowed their population to increase very rapidly. By the second week of July they were very abundant. About the end of July they formed ephypia and their population appeared to decline. This reduction is associated with the reduction in phytoplankton abundance. After early July, *D. pulex* constituted the major food item of the rainbow trout. Before then and all during 1969, the trout fed almost exclusively on *Chaoborus* spp. larvae and pupae. From early July through mid-August, *Chaoborus* were a secondary trout food item. By the end of August, trout ingested *D. pulex* and *Chaoborus* in about equal proportions. This is especially interesting since *Chaoborus* also became more abundant after aeration began, and *Chaoborus* are larger than *D. pulex*.

The small cladocera, *Bosmina* spp., and medium-sized cladocera, *Diaphenosoma* spp. and the copepod *Diaptomas* spp. were virtually untouched by rainbow trout at any time although they were very abundant. These observations agree well with those of Galbraith (1967). He found that rainbow trout in two Michigan lakes feed almost exclusively on

Daphnia greater than 1.3 mm. This predation led to the near extinction of Daphnis pulex in one lake and apparently favored the survival of smaller species of zooplankton. Hall (1964) demonstrated that fish predation accounted for as much as a 25% per day loss from the Daphnia galeata mendotae population in a southern Michigan lake. Predation on sub-adult individuals is critical to their survival and is probably the major factor leading to the extinction of D. pulex and other zooplankters that mature at a larger size.

My observations conflict somewhat with Brooks and Dodson's (1965) size efficiency hypothesis: namely, that planktiverous fish generally decimate the larger zooplankton species and thus favor the survival of smaller species. In Hemlock, this hypothesis may effectively apply to the D. pulex, Bosmina, Diaphanosoma and Diaptomas group, but not to D. pulex and Chaoborus. Chacborus is much larger than D. pulex, but D. pulex appears to be the much preferred food item, even though Chaoborus were much more abundant after aeration than before. Chaoborus larvae and pupae constituted over 90% by volume of the trouts' diet before aeration began, but about only 5% to 50% after aeration. D. pulex constituted 50% to 95% after aeration.

Chaoborus were much larger on the average before than after aeration began. This change in average size could be due to species shift (Table 6) and/or to increased production rates. Increased production following aeration would skew the size distribution, with the smaller instars becoming more abundant. Even though the *Chaoborus* average size decreased following aeration, they were still much larger than *D. pulex*.

These findings suggest that factors other than absolute size are directing food selection by the trout. *Chaoborus* are more transparent than *D. pulex* and may therefore have a smaller "effective" size. Likewise, their particular diel migration pattern and habit of nestling in the mud may reduce their vulnerability. Rainbow trout very seldom feed on the benthos. Galbraith concluded that rainbow trout feed selectively, rather than merely straining plankton from the water. My findings tend to substantiate his conclusion.

Cladocera and other zooplankters commonly exhibit diel vertical migrations (Cushing, 1951; Hardy, 1956; Wynne-Edwards, 1962). I did not try to measure their migration in Hemlock Lake. The typical pattern is for the zooplankter to inhabit the dimly lit depths during the day, and the surface waters at night. Some zooplankton have just the opposite behavior, or do not migrate according to any fixed pattern. In our case, *D. pulex* and *Bosmina* appear to conform to the typical pattern. Since both collections were made during the day, we would expect the zooplankton that migrate in the usual pattern to be concentrated near the bottom of the lake, or at some gradient barrier (Harder, 1968). *D. pulex* was most abundant near the bottom of the lake after aeration, whereas *Bosmina* was most abundant within the metalimnion, during both collections. *D. pulex's* distribution was not related to the temperature gradient, but Bosmina's distribution apparently was. The distribution of the other zooplankters after aeration did not appear to be related to the temperature gradient.

One common hypothesis to explain vertical migration is that the zooplankton migrate to escape predation by sight feeders. Those inhabiting the depths during the day are less conspicuous than those in shallow water and predation is thus reduced on the deep-living individuals. They migrate to the surface under the protection of darkness to feed. Their upward movement generally coincides with sunset, while their downward movement is initiated or timed by sunrise. In our case, rainbow trout and Chaoborus are probably the two most important planktivores. Of these two, the trout are probably the most important and feed largely on the D. pulex. Furthermore, trout feed on Chaoborus and thereby reduce the latter's predatory impact. Since the other zooplankter species were not preyed upon by the trout, there was probably no incentive for them to migrate. They could, therefore, inhabit the surface waters during the day and thereby prolong their grazing time. If anything, it might have been advantageous to disperse throughout the lake or migrate to the depths after dark to avoid possible predation by Chaoborus.

In El Capitan Reservoir, California, copepods responded to artificial destratification by concentrating along the bottom during the day (Fast, 1971). They were formerly restricted within or above the metalimnion by oxygen depletion. The threadfin shad (Dorosoma petenensa) was very abundant in this lake and large zooplankters were scarce. Small copepods constituted about 90% of the net zooplankton. The Hemlock copepod adults did not concentrate at the bottom after aeration. The reason for this is not clear. It could be related to the temperature gradient, or some other factor such as lack of significant predation on their population. Predation pressure could be an important factor affecting zooplankton migration behavior. It could partly explain why a given species may migrate in one situation, but not in another.

Any future investigation of this aeration system should include a more thorough evaluation of the zooplankton responses. A detailed investigation was not included in this case because I felt responses in the zoobenthos and other components of the biota would be more important, and require less effort to measure. Although significant changes did occur in these other components, they were not all as rapid or spectacular as those changes in the zooplankton.

Zoobenthos

Benthic organisms are sensitive indicators of changes in their environment. These organisms may respond in one or more ways depending on the nature and intensity of the environmental change. These responses are interrelated and include changes in: standing crops, growth or metabolic rates, species composition, species dominance, depth or spatial distribution, survivorship, reproductive rates and behavior. Changes in standing crop, species composition and distributions are most easily measured. Most studies have concentrated on these parameters and at best tried to infer changes in the other parameters. Changes in the other parameters are presently difficult or impossible to measure accurately.

Zoobenthos analyses are notoriously laborious. On the average, each sample required over two hours of laboratory and field work. This includes: collecting, sieving, sorting from the sediments, sorting each taxa into separate vials, counting each taxa, weighing each taxa and statistical analysis.

Probably the single most important zoobenthic parameter is its yearly production rate. From this you may infer how much energy passes through this ecosystem component. This information relates directly to how much energy was fixed by the plants, and how much energy was made available to higher trophic levels such as fishes. Ball (1948) found that invertebrate production is related to fish production.

Good estimates of total zoobenthos production are impossible with our present knowledge and technology. Most studies estimate zoobenthos standing crop, and possibly some parameter of production such as adult emergence. From this they infer rates of production. A few studies attempt to measure the productivity of a given species of zoobenthos (Cooper, 1965; Hilsenhoff, 1967) but overlook changes in the total benthic fauna assemblage. From the standpoint of total energy flow, total zoobenthos production is much more important and the production of particular species may be relatively inconsequential. At present we cannot accurately measure production rates of some organisms such as oligochaetes or nematodes. We have methods for measuring production of some organisms such as the midges, but the techniques are greatly complicated by multivoltine species populations, different generation times for each species or even with a given species, rarity of some species and ineffectual sampling methods. Crayfish production is relatively easy to measure, but requires different sampling techniques than are generally used to measure zoobenthos standing crops. Crayfish are omnivorous, feeding mostly on plant material and detritus. Their trophic position is similar to other zoobenthic organisms, but their production rates or standing crops are seldom measured because of sampling problems. Momot (1967) found that their production may be more than eight times as great as the total production of other zoobenthos. Even for species where techniques of estimating production are available, the techniques differ greatly. Therefore, separate sampling programs, etc. may be necessary to measure production of more than one taxa. This leads to exceptionally large expenditures of time and money and has not yet been attempted.

Because of the foregoing considerations, I chose to measure zoobenthos standing crops, and emergence rates of certain taxa. From these data I hoped to infer in a larger sense what changes occurred due to artificial aeration. In fact, most of our time was devoted to the analyses of the zoobenthos.

Between-sample variances are generally very large and non-homogeneous. With the possible exception of the Chaoborus larvae, there were not significant differences between numbers or biomasses of specific taxa on any given date. Even though trends are evident, their statistical verification is not possible because of sample variance. Variances were not only large in most cases, but non-homogeneous and not a function of sample size. This problem invalidated the use of certain powerful statistical tests. However, I still feel we can draw some conclusions from trends in the data, keeping in mind that their conclusions are not statistically valid in all cases at the usual significance levels.

Increased primary production generally increases zoobenthos production and standing crop. Tanner (1952) found a large increase in Hemlock Lake's phytoplankton and zoobenthos standing crops during artificial fertilization. He added 71.5 kg of inorganic fertilizer to Hemlock during 1949, and 56. kg during 1950. Zoobenthos total numbers (standing crop) increased 980% in 1949 compared to 1948, and 400% in 1950 compared to 1948. Chironomidae accounted in large part for this increase. They increased 1078% the first year. All other zoobenthos taxa also increased, but not at the same rate. This led to changes in zoobenthos species composition. Before fertilization, Anisoptera were dominant in terms of biomass. After aeration, Trichoptera, Ephemeroptera and Chironomidae were more abundant. Tanner attributed these changes to increased primary production. Secchi disc transparency decreased from between 3.1 m and 4.6 m before fertilization to less than 1.5 m after. In this lake, secchi measurements are representative of phytoplankton density.

Zoobenthos standing crop and production rates apparently increased during artificial aeration of Hemlock Lake. Total numbers of zoobenthic organisms almost doubled. Total biomass decreased slightly, but not for the more important species. Relatively unimportant, but large leeches comprised 25% of the biomass during 1969 but less than 1% during 1970. Only one leech was captured each year. Total midge emergence more than doubled during aeration, indicating increased production rates. I attribute these increases to increased sediment decomposition and primary production, and increased "lebensraum." These increases are directly attributed to artificial hypolimnion aeration.

Hemlock Lake's zoobenthos populations were mostly restricted to the epilimnion, in depths less than 4.6 m during 1948-50 (Tanner, 1952). Artificial fertilization did not greatly affect their summer depth distribution although metalimnion and hypolimnion oxygen concentrations were greatly reduced and the metalimnion depth became shallower. Depth of oxygenated water decreased to about 75% of its former value following fertilization, and the average metalimnion depth decreased from 6.8 m before 4.5 m after fertilization. This increase in anoxic conditions and shoaled metalimnion should lead to decreased living space and increased rates of organic sedimentation. Organic matter settling within the anaerobic zone does not readily decompose and is essentially unavailable to higher trophic levels. Artificial fertilization also increases the availability of organic production within the epilimnion and more than compensated for the potential losses from the system due to anaerobiosis.

Artificial hypolimnion aeration not only increased primary production, but it increased the availability of former organic production. Increased primary production occurred inadvertently due to technical oversights. This response may be avoided by use of different aerator designs and construction. Increased availability of previously produced organic matter, on the other hand, was a primary goal. Before aeration much of the lake was uninhabited and underexploited by the zoobenthos due to anaerobiosis. This accounts in part for the highly organic profundal sediments. The peat bottom developed in part because the browsers and decomposers could not utilize all the allochthonous and autochthonous inputs of organic matter. McConnel (1968) found that allochthonous organic litter contributes a significant food input to Pena Blanca Lake, Arizona. Based on an estimated ecological efficiency of 0.56%, he estimates that this input may account for as much as 16.7% of the yearly largemouth bass (Micropterus salmoides) harvest. The lake's bottom, and other eutrophic lake bottoms like it, have become depositaries for organic materials and nutrients. Anaerobiosis accelerates the rate of accumulation and filling of the lake. After aeration, the entire lake bottom was again accessible to aerobic decomposers and macro-zoobenthos. Midges rapidly invaded the profundal zone and capitalized on the rich supply of organic materials. Certain other benthic organisms such as the mayflies and Odonata did not invade the hypolimnion after aeration. This may be due to low water temperatures, positive phototaxis, preferred food concentrations, shelter, sediment composition or some other factor.

Artificial hypolimnion aeration should lead to accelerated decomposition of the profundal sediments. Increased oxygen will favor aerobic decomposers which are more efficient than anaerobic, and increased temperatures will accelerate decomposition. Increased bacterial production and concentration, plus their increased availability may lead to increased production of macro-zoobenthic organisms such as chironomidae and oligochaetes that feed on micro-organisms.

Only four oligochaetes were collected during 1969 compared to 267 during 1970, and many of these latter worms were in the profundal zone. Chironomids were also more abundant in the profundal zone after aeration. Wirth et al. (1970) and Ogborn (1966) reported increased biodegradation of organic sediments following artificial destratification of eutrophic reservoirs. Their observations are qualitative rather than quantitative, however, since biodegradation of sediments is very difficult to measure. Increased biodegradation and the subsequent incorporation of this energy into the higher trophic levels is a form of energy "recycling". Energy that was formerly stored via organic compounds and lost to the system is brought back into the system by artificial aeration. This process may increase the overall lake productivity to a level that cannot be sustained on a long-term basis. Productivity may therefore decrease as the organic materials are oxidized.

Artificial aeration may cause a net energy loss from the profundal sediments on a short-term basis, but not on a long-term basis. Nutrient exchanges with the sediments may follow a similar pattern. Under anaerobic conditions, phosphorus and other nutrients are solubilized and a net movement occurs from the sediment to the water (Mortimer, 1941). At the spring and fall turnovers, these nutrients are distributed throughout the lake. These turnovers also distribute oxygen throughout the lake, oxidize the mud surface layers and at least temporarily cause a net influx of nutrients into the mud. Fitzgerald (1970) found that aerobic muds have a considerable capacity to remove phosphorous from the water by sorption. Four tenths g (dry wt) of mud sorbed 0.05 mg PO_4-P in less than 30 min. Artificial hypolimnion aeration should not only oxidize the mud surface and increase its sorption capacity, but it will pass water over the mud and thereby increase contact between mud and water. Macrozoobenthos also increase the oxidation rate by burrowing into the mud and pumping water through their burrows. This will greatly increase oxidation over that expected from diffusion and also increase biodegradation. Chironomid larvae may burrow 50 cm or more into the sediments (Hilsenhoff, 1966). Chironomus riparius increased the oxygen supply to the sediments and increased the redox potential by circulating water through its burrow (Edwards, 1958). This circulation is maintained to provide oxygen for respiration and food. Oligochaetes are also active burrowers and probably exceed that of the midges in both extent and duration.

The effect of artificial aeration on the profundal nutrients is open to question. Hasler (1963) found that circulating water in an aquarium over mud, increased the phosphorus content of the water. Furthermore, the artificial destratification of El Capitan Reservoir, California did not appear to reduce phytoplankton primary production (Fast, unpublished data), indicating that nutrient availability was not decreased. Other factors such as water volume increase complicated this evaluation, however. The mechanism by which phosphorus, or certain other nutrients, would be transferred from the profundal muds is unknown. It may well be that significant quantities of nutrients may be regenerated under both anaerobic and aerobic conditions. In the first case regeneration is a function of redox potential. In the latter case regeneration may be related to the amount and kind of organic matter and its rate of decomposition. The former process could account for the June 1970 plankton bloom, and the latter process for the August 1970 bloom. It is my opinion that long-term artificial aeration will result in the net transfer of nutrients into the mud as their energy source is depleted, and a commensurate decrease in the primary productivity of the lake. Mechanisms affecting nutrient transfers and rates of transfers within lakes are presently very poorly understood. Until we understand and evaluate rates of transfer, we will be greatly hindered in our understanding of lake ecology.

The primary method by which the Chironomidae invaded the hypolimnion is unknown. They probably arrived by two methods: Dispersion of eggs and just-hatched larvae, and active migration of the late instar larvae. Eggs are generally broadcast over the entire lake's surface (Hilsenhoff, 1966). They may settle and concentrate in certain depth zones (Bardach, 1955; Gleason, 1961), but their development at the settling site depends on environmental factors. Even the eggs of low oxygen tolerant species such as *Chironomus decorus* (Gleason, 1961) or *C. plumosus* (Augenfeld, 1967; Dugdale, 1955) will not hatch in the absence of oxygen. Newly hatched larvae of *C. plumosus* are free-swimming and strongly phototropic in the absence of a suitable substrate (Hilsenhoff, 1966). In the presence of suitable substrate their phototropism diminishes and they remain in the mud. Furthermore, the growth and density of the Chironomids depends on the quantity and quality of the food supply. Gleason found the greatest concentrations of *C. decorus* in the zone receiving the greatest concentration of fresh sediments including a high percentage of phytoplankton. Jonasson and Kristiansen (1967) found that availability of fresh phytoplankton and oxygen concentration were the two most important factors affecting the growth of profundal *C. anthracins* in Lake Esrom, Denmark. Their growth was mostly limited to times of spring and fall turnover when phytoplankton production was maximum and oxygen plentiful. Growth during the summer was inhibited by low oxygen levels and poor quality of the food. Food reaching the bottom was partly decomposed, and under low oxygen levels the larvae either spent much time in respiratory activity, or became lethargic. Dugdale (1955) also found that *Chironomus plumosus* growth and emergence is mostly restricted to spring and fall when profundal oxygen and temperatures are greatest and presumably food is optimal.

Later instar Chironomid larvae may actively migrate to the profundal zone. Dugdale (1955) found mature larvae swimming between the surface and bottom shortly after sunset. Mundie (1959) found Chironomid larvae swimming at the surface of Lac La Ronge, Saskatchewan, Canada. Early and late instars were found mostly over 5 m of water or more and consisted of 60% Chironomini, 25% Tanypodinae and 15% Orthocladinae. Active migration of Chironomid larvae could lead to a rapid invasion of a new habitat. There is some evidence that late instar larvae invaded Hemlock's profundal zone soon after aeration began. Procladius denticulatus emerged from between 16 and 18.6 m during the first week of July 1970, after two weeks of aeration (Figure 50). Their emergence during 1969 was restricted to 12 m or less. Tanypus spp. emerged from between 8 and 12 m by mid-July 1970 and from between 16 and 18.6 m during August. During 1969 Tanypus emergence was restricted to less than 4 m. Both these species are predaceous, and migratory by nature (Miller, 1941). Miller found that Procladius emerged from all depths of Costello Lake, Ontario at about the same time during June and July. He suggests this syncronous emergence is due to larvae moving back and forth through the metalimnion in search of prey. Larval development is partly related to temperature. Larvae moving back and forth would thereby be exposed to about the same average temperatures, develop at about the same rate and emerge at about the same time. Other non-predaceous midges emerged from the profundal zone, but not as soon as Procladius. Third and fourth instar larvae of Chironomus tentans were observed below 18 m during July even though their adult form was never collected, even in shallow water.

Hemlock's zoobenthos standing crop is impoverished considering the level of primary production in this lake. Total numbers and biomass collected during 1969 were 2,396 and 2.41360 gms, respectively (Table 5). Although Section Four Lake appears much less productive, total numbers and biomass collected during 1969 were 17,609 and 11.09227 gms. Before fertilization, Tanner (1951) found averages of 83.5 organism/m^2 in Section Four. During this same period in Hemlock, he found only 48.5 organisms/m^2. The reasons for this impoverishment are not obvious, but are probably due in part to fish predation and the nature of the substrate. Fish predation can greatly limit the zoobenthos standing crop (Ball and Hayne, 1952; Wilkins, 1952). Tanner (1951) observed a sharp decrease in the zoobenthos standing crop during the second year of fertilization of Hemlock and three other neighboring lakes. He attributes these decreases to enhanced survival of minnows during the first year of fertilization. The bluntnose minnow and redside dace were very abundant in Hemlock during 1969 and 1970. They were restricted to shallow depths, generally less than 4 meters, and mostly near shore. I concur with Tanner's conclusion that minnow predation on the zoobenthos greatly reduces zoobenthos standing crop in shallow water but not in deep water after aeration.

Some other factor is more important in the profundal zone. The small profundal standing crop after aeration is partly due to migration rates. These apparently are slow. We witnessed a gradual increase during the summer, but profundal standing crop probably did not reach its maximum value by September 1970. Even with complete destratification of El Capitan Reservoir, California profundal standing crop did not appear to maximize until the second summer of destratification (Fast, unpublished data). If we had started aeration much sooner during 1970, it might have increased more rapidly. Many species reproduce and become established during May and early June. The hypolimnion was anoxic during this period, and the organisms were probably well-established in shallower depths before we began aeration June 14th.

The nature of the sediments may be another reason for the general impoverishment of Hemlock's zoobenthos standing crop, and the slow profundal invasion rate. Bog lakes, or lakes with abundant peat deposits, typically have impoverished zoobenthos populations. Hilsenhoff and Narf (1968) correlated 14 physical-chemical parameters with standing crops of 13 species of midges, Ostracoda and Copepoda in the profundal zone of 14 Wisconsin lakes. They found significant negative correlations between organic matter in the mud and standing crops of copepoda, ostracoda, Palpomyia and Chironomus plumosus. The reasons for this are unclear.

In theory, this mass of organic matter should provide an abundant food supply. In practice, it seems to inhibit zoobenthic organisms. Three likely explanations are: (1) The rich organic matter has a high carbon dioxide content which inhibits oxygen utilization by the midges. High carbon dioxide concentration sharply inhibits oxygen utilization by fishes (Black et al., 1954). This may also apply to certain zoobenthic species. Midges collected from anoxic hypolimnions are typically relaxed and extended, which is a sign of respiratory distress; (2) The accumulated plant material possesses some inhibitory or antibiotic substance that either directly affects the macro-zoobenthos or bacteria used as food by the macro-zoobenthos. The plant detritus accumulation is evidence that bacterial decomposition is not optimum. This may be due to low nutritional value of the detritus, or due to inhibitory substances. Hilsenhoff and Narf also found a highly significant negative correlation between organic matter in the mud and pH of the mud. Highly organic muds had low pH, some being below 6.0. A highly significant correlation existed between organic matter in the mud and water content of the mud, and a highly significant positive correlation between pH of the mud and pH of the water. Low pH may be due to carbonic acid, humic acid or some other acid associated with the organic matter. Low pH in itself could deleteriously affect zoobenthos; and/or (3) highly organic bottoms are often flocculant. Midge are positively thigmotactic, requiring contact with a substrate.

The high water content may not provide adequate contact for the midges or facilitate tube building.

Differences in average Chironomid larval size at different depths was most pronounced. Shallow water larvae were much smaller than deep-water larvae. On September 4, 1970, only 5% of numbers of Chironomid larvae were found below 14.5 m, but these comprised over 15% of the biomass (Figures 43 and 44). This condition is undoubtedly a result of different species complexes at different depths. This gradation in size from small species in shallow water to large species in deep water is often found in moderately and highly productive lakes (Brundin, 1951 and 1953). Large larvae can better cope with oxygen microstratification at the mud-water interface because of their greater capacity for circulating water. This circulation disrupts the microstratification and provides oxygen to the larvae. Furthermore, large larvae of the Chironomus type contain hemoglobin and can withstand anaerobiosis for extended periods should the oxygen microstratification lead to more general hypolimnion stagnation.

Although oxygen microstratification was not investigated, it seems unlikely that this developed to any appreciable extent after aeration began. Water currents, especially near the aerator should have kept it to a minimum. If this is true, then the carbon dioxide and BOD of the sediments could have been the main factor. In either case, large larvae would be favored because of their greater respiratory activities

The extent of oxygen depletion greatly affects the kinds of midges found in a lake. Indeed, lakes may be classified according to their midge populations (Lenz, 1925, 1927; Lundbeck, 1926, 1936; Brundin, 1953). Unproductive lakes are characterized by Tanytarsus midges. These midges are small and lack hemoglobin. They are very intolerant to low oxygen concentrations, and are apparently better adapted for survival in oxygen-rich lakes than are Chironomus midges. Chironomus midges are typical of rich lakes that often develop oxygen deficits within the hypolimnion. Bryce (1965) found different species complexes in 17 shallow English acid peat pools. Nine pools were dominated by Tanytarsus, while seven other pools were dominated by Chironomus. One pool was intermediate with about equal proportions of both species. All but one pool was less than one meter deep. pH ranged between 4.0 and 6.0. Bryce did not indicate what factors seem to be responsible for the species complexes.

Interestingly enough, oxygen concentration of the water does not appear related to organic content of the sediments. Hilsenhoff and Narf (1968) found no correlation. Hargrove (1969) also found no significant relationship between these variables. He found that sediment oxygen consumption is by the microbiota and that the consumption rate is temperature-dependent. The rate was also accelerated by stirring when oxygen concentrations fell below 6.0 mg/l.

Hemlock Lake's position on the Tanytarsus-Chironomus scale is unclear. Tanytarsus accounted for 27% of the emergence during 1969, but only 8% during 1970. Most of the other species, and certainly _Chaoborus_, are indicative of rich _Chironomus_ type lake. Indeed, different analyses of the water indicate oxygen-limited conditions in the profundal zone and high BOD of the sediments at all depths. The true picture may be obscured by incomplete data. We probably missed much of the total emergence because of our sampling schedule.

Chaoborus are often categorized as benthic organisms, but at other times as planktonic. In fact, they are both. The first instar larvae are strictly planktonic and typically inhabit the lower epilimnion and metalimnion. They are non-migratory. Second and third instars are also planktonic and exhibit weak diel migration. Some third instar larvae inhabit the profundal muds. Fourth instar larvae have a definite diel migration pattern (Teraguchi and Northcote, 1966; Roth, 1968). Typically they nestle in the profundal muds during the day and migrate to near the surface after dusk to feed. About dawn they descend into the mud again. This migration is apparently temperature dependent. They do not migrate during the winter. During early spring a small percentage migrate, but during mid-summer migration is maximal. However, even at that time a certain percentage of the population may remain in the mud at night. Laboratory tests indicate this diurnal rhythm is endogenous, but partly controlled by light and temperature (LaRow, 1968).

The diurnal activity pattern persisted as long as 10 days under total darkness in the laboratory.

Although Chaoborus larvae are relatively insensitive to low oxygen concentrations, they will avoid highly anoxic conditions such as those found in the monimolimnion of Hemlock during 1969. They are often found below the level of oxygen depletion, during summer and winter, and are apparently unaffected by winterkill conditions (Northcote, 1964). During the summer, fourth instar larvae may remain in the deep water during the day rather than nestle in the deep profundal muds (Teraguchi and Northcote, 1966), presumably because of highly anoxic conditions. In other lakes no fourth instar larvae are found in the water during the day (Roth, 1968).

Their total distribution in Hemlock Lake is not known since we did not adequately sample their planktonic distribution. It is likely that a larger percentage of the fourth instar larvae remained in the water during the summer 1969, compared to 1970. Dredge and emergence trap samples indicate relatively few larvae below 14.5 m during 1969. Some of those supposedly captured below 14 m may actually have been entrapped by the samplers as they were lowered. In any event, Chaoborus emergence was restricted to 4 m or less during 1969, but extended to all depths during 1970.

If fourth instar larvae were more planktonic during 1969 than during 1970, we may have underestimated their relative abundance during 1969. Benthic samples indicate a much larger population during 1970. Emergence data also indicates a much larger population during 1970. Chaoborus constituted 11% of the total midge emergence during 1969, but 28% during 1970. Their total numbers increased from 47 during 1969 to 296 during 1970. These data indicate a significant increase in Chaoborus standing crop and production rate during aeration.

Increased Chaoborus production may be related to increased food, less severe environmental conditions, and reduced predation by fish. Chaoborus' preferred prey are copepods, but they also feed on cladocera, chironomid larvae, mosquitoes and other Chaoborus larvae (Stahl, 1966). Increased densities occurred in all these categories (except mosquitoes) during artificial aeration. Although they can tolerate anoxic conditions, they probably are less restricted under aerobic conditions. Under aerobic conditions a larger percentage may have nestled in the mud and thus reduced their vulnerability to predation. There was a large increase in the number of larvae found below 14 m after aeration. Over 90% of the larvae were found below 14 m during late August and September 1970, compared to less than 20% during 1959 (Figures 56 and 57). As noted, Chaoborus avoid highly anoxic conditions. Highly anoxic conditions were eliminated by aeration during 1970. Chaoborus were by far the most important trout food item before aeration began. After aeration, trout fed more on Daphnia pulex. This reduced predation rate undoubtedly contributed to their population increase.

The shift in Chaoborus species composition from C. flavicans to C. punctipennis is dramatic. C. flavicans is much larger than C. punctipennis and was the only Chaoborus adult found during 1969. Almost twice as many C. flavicans emerged during 1970 compared to 1969, but almost three times as many C. punctipennis emerged during 1970 compared to C. flavicans. Some environmental change could have favored this shift. C. punctipennis, being smaller, may have fed more efficiently on the small zooplankters such as Bosmina that increased significantly during aeration.

Crayfish

Orconectes virilis depth distributions during August 1969 differ markedly from those described by Momot (1969) and Momot and Gowing (1970) for nearby lakes, and from the August 1969 Section Four crayfish distributions. In these other lakes, the females were found in deeper water than the males. In Hemlock Lake, the females were more abundant in shallow water. Momot (1967) proposed that the females' migration to deeper water is associated with their sexual maturation. Low temperatures and light intensity are associated with sexual maturation. It is difficult to draw definite conclusions from my data because of small sample sizes and lack of information on age distribution. Yearlings apparently respond differently than mature animals. However, these data indicate that there is an avoidance of the males by the females. The males have moved into deeper water, possibly causing the females to move into shallow water. The females apparently avoided moving into still deeper water than the males because of the low temperatures. Less than 10% of the crayfish were found below 6 m at temperatures less than 13°C. Momot (1967) found that O. virilis also avoided temperatures of less than 13°C. In Section Four Lake, 10°C was the lowermost temperature limit.

Depth distribution changes during 1970 are most difficult to explain. Before aeration began, their distributions were as expected. Over 95% were in 0 to 4 m depth at temperatures above 10°C. This distribution is similar to those found in the other lakes at this time of the year. After aeration began, oxygen concentration did not limit their maximum depth distribution nor did temperature seem to limit them to shallow depths. Hypolimnetic temperatures warmed to over 16°C by August 20, 1970, but crayfish were not found below 10 m. Some factor other than oxygen or temperature seemed to limit their depth distribution. After the lake destratified in late August, they distributed to the bottom. This indicates that the inhibitory factor was either distributed evenly throughout the lake, or eliminated by destratification. There are also no obvious differences in distribution between males and females during 1970.

Rainbow Trout

Rainbow trout were restricted to levels above 8 meters during 1969 by hypolimnion stagnation. Their upper limit was related to the 21°C isotherm. Over 90% of the fish were captured between these two restraints. Before aeration began during 1970, these fish were again restricted to shallow water by anoxia, but quickly extended their depth distribution as the anoxia was eliminated. An oxygen deficit as well as other chemical gradients are associated with anoxia. Hydrogen sulfide, carbon dioxide, ammonia and other detrimental substances are present in high concentrations below the oxygen depletion depth. The trout undoubtedly reacted to these factors and others in avoiding the anoxic water. Black et al. (1954) have shown that carbon dioxide above certain levels sharply inhibits oxygen utilization by fishes. The carbon dioxide concentration at which this inhibition becomes most apparent is species specific. Fish adapted to low oxygen levels, such as the brown bullhead (Ictalurus nebulosus) are not as readily affected by carbon dioxide.

The depth preferences of the 1969 stocked trout are not well defined after mid-July 1970. They seem to prefer the bottom during late July and early August 1970, and then distribute throughout the lake after late August. However this pattern may be an artifact of small sample size.

The results of the acclimatization tests during 1970 are puzzling. The rainbow trout distributed throughout the lake very soon after release and did not show preferences based on their acclimatization history. While these fish were held in the cages they should have been acclimating to several factors. These factors include temperature, light, pressure, oxygen, carbon dioxide, and possibly scent. Intuitively I expected temperature, light, pressure and scent to be the most important factors. Many people have demonstrated species specific temperature preferences in both laboratory and field tests. Although a given species will occupy a wide range of temperatures, it generally will prefer and seek a given temperature. Bardach and Bjorklund (1957) found that fish could detect temperature changes as low as 0.05°C/min. Changes of 0.2°C/hr. were apparently not detected. They trained fish to respond to temperature changes and thereby demonstrated that fish can detect smaller changes than they generally respond to. Various researchers have found that light (Sullivan and Fisher, 1953; Brett, 1952; Pearson, 1952), feeding activity (Brett, 1952; Pearson, 1952) and social behavior (Pearson, 1952) can interfere with temperature selection. Hasler (1966) clearly demonstrates fishes ability to detect and respond to scents. Pressure acclimation can also severely limit short-term vertical movement of fish responding to temperature differences. Phyoclists, fish with closed swimbladders, are especially restricted against rapid upward movement above their equilibrium depth. Jones (1952) estimates it would take Perch (*Perca flavescens*) 50 hours to adjust to a 90% hydrostatic pressure reduction. Downward movement would be less restricted. Physostomes, fish with an open duct connecting the swimbladder with the alimentary canal, are much less restricted in their vertical movements. The expanding air associated with rapid ascent can be readily vented through the mouth. The re-secretion of air following descent is a slow process however (Ledebur, 1937). Hodgson and Richardson (1949) report the ascent of prichards from 15 to 7 meters in 3 minutes. Prichards are marine Physostomes. Northcote et al. (1964) observed marked diel migrations of sockeye salmon (*Oncorhynchus nerka*) and peamouth chub (*Mylocheilus caurinus*) in a British Columbia lake. The fish migrated over 10 meters and through a $4^{\circ}C$ to $6^{\circ}C$ temperature difference in less than 6 hours. Their estimates of fish depth distribution from gill nets agreed well with their echo sounding observations. Although they could not document explanations for these migrations, food selection appears to be an important factor.

Rainbow trout are physostomes and presumably capable of rapid vertical movements. This ability should allow them to rapidly respond to vertical temperature differences or other factors affecting their depth distribution. This ability allowed them to rapidly disperse throughout Hemlock lake soon after release. Unfortunately we have no estimate of their diel depth distribution. I would expect their diel distribution to agree closely with the diel distributions of their prey.

Garside and Tait (1958) and Ferguson (1958) demonstrated by laboratory tests that temperature alone can determine the depth distribution of fishes. Their temperature preference is related to their recent thermal history as well as genetically defined factors. Fry (1947) defines their preferred temperature, or short-term preference, as the "region, in an infinite range of temperature, at which a given population will congregate with more or less precision." This short-term preference is related to their recent thermal history. He also defines the final preferendum temperature as "a temperature around which individuals will ultimately congregate, regardless of their thermal experience before being placed in the gradient." The final preferendum temperature, or long-term preferred temperature, is largely species specific, although the final preferendum temperature varies greatly with size and age for a given species. Younger fish usually have a higher final preferendum temperature. The final preferendum temperature is usually measured as the point at which the preferred temperature equals the acclimation temperature. Fish acclimated above the final preferendum will generally prefer cooler temperatures, whereas those acclimated below the final preferendum will generally prefer warmer temperatures. Ferguson (1958) observes that the laboratory determined final preferendum temperature is usually greater than the temperature selected by most fish species in nature. He attributes these discrepancies to use of younger fish in the laboratory studies than were observed in nature. Fry (1937) found in nature that the young cisco (Leucichthys artedi), tended to remain in the warm shallow water, while the older fish moved into deep cooler water. The selected temperature in nature can also be altered by physical or chemical limitations such as oxygen depletion (Dendy, 1946, 1948; Botges, 1950).

The degree of thermal gradient may also be an important factor affecting response to temperature differences. Although this has not been well documented for fish, Beeton (1960) found that vertically migrating Lake Michigan Mysis relica would not penetrate a thermal gradient of 1.67°C to 2.0°C/m, but some would penetrate a 0.66°C to 0.94°C/m gradient. The latter individuals soon returned below the gradient, however. During isothermal periods they would migrate uninterrupted from the bottom to the surface. Whether this response is due to preferred temperature, temperature gradient or density discontinuity, is unclear. Harder (1968) found many marine zooplankters reacted to discontinuities in stratified laboratory cylinders. These discontinuities included density gradients due to temperature, salinity and density without temperature or salinity gradients. Some organisms react more to these discontinuities than others. Littorina spp. veliger larvae were distributed almost entirely at the discontinuity, while young mysids did not significantly change their distribution after a discontinuity was imposed. The mysids' negative phototaxis probably outweighed their possible positive response to the discontinuity.

Garside and Tait (1958), using 10 to 15 cm fish in laboratory tanks, observed a 13°C final preferendum for rainbow trout. This does not agree with the rainbow trout temperature selections found by Horak and Tanner (1964) in Horsetooth Reservoir, Colorado. There the trout were most numerous in 18.9 to 21.1°C water. Although they ranged throughout the reservoir, in temperatures from 7.7 to over 22°C, over 93 percent were found in or above the metalimnion in temperatures above 10°C. Hypolimnetic oxygen, pH, carbon dioxide or bicarbonate alkalinity did not appear limiting. These trout were larger than those used by Garside and Tait, ranging in length from 15.7 to 62.5 cm. Larger fish usually prefer cooler temperatures. Although many factors undoubtedly affected their depth distribution, Horak and Tanner felt that food selection was a major factor affecting the trout depth distribution. Although copepods were more numerically abundant than cladocera (54.5% to 45.5%), the trout fed selectively on cladocera. The cladocera were mostly distributed above the thermocline.

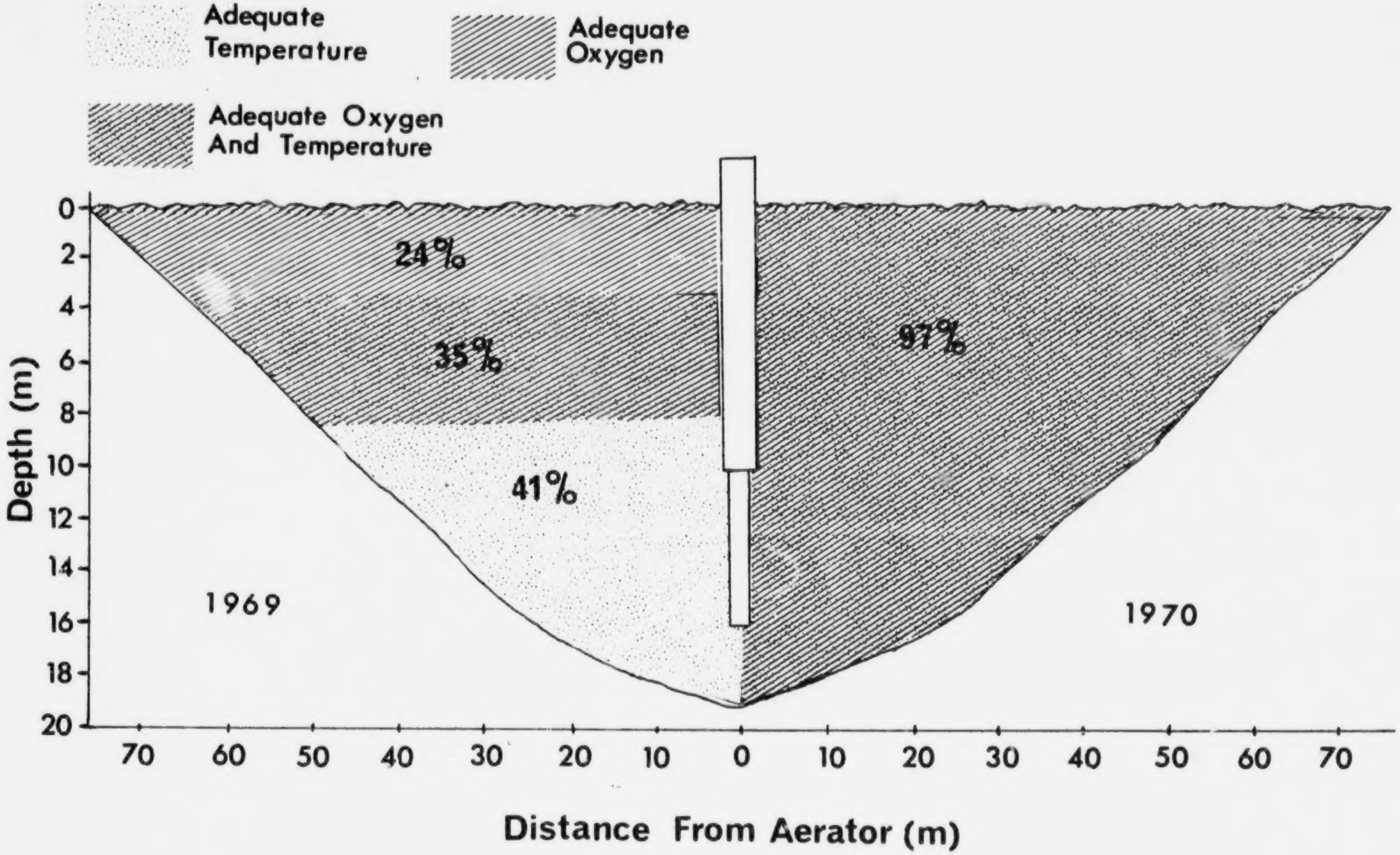
Hemlock Lake rainbow trout fed almost exclusively on _Chaoborus_ larvae and pupae and _D_. _pulex_. Both organisms are known to exhibit diel vertical migrations. They inhabit the deep, dimly lit regions of the lake during the day, and the surface waters at night. They are presumably most vulnerable to trout predation during dawn and dusk, the periods of their vertical migrations.

The vertical migration of the trout as response to the vertical migration of their prey could largely explain the widespread distribution of the trout after aeration began. Burbige (1969) found that the American smelt (Osmerus mordax) underwent a vertical migration within the hypolimnion in response to their major prey species, Chaoborus. Although Chaoborus migrated from the bottom of the lake to the surface, the smelt did not penetrate the thermocline. Galligan (1962) found that lake trout (Salvelinus namaycush) greatly altered their depth distribution in response to their prey's depth distribution. Normally the trout preferred 24 to 31 meter depths, but invaded 6 to 24 meter depths in response to spawning alewife (Alosa pseudoharengus) on which they preyed heavily. It is my conclusion that as long as certain physical, chemical, or behavior factors do not absolutely limit the distribution of fishes, then the fishes will distribute in response to their prey's distribution.

We can define adequate oxygen and temperature conditions for trout as oxygen concentrations above 5.0 mg/l and temperatures less than 24°C. Trout can withstand temperatures as great as 26.7°C for a few days, but prolonged temperatures above 24°C lead to high mortality (Eipper, 1960).

Likewise, they may also withstand oxygen concentrations of less than 5.0 mg/l at low temperatures, but 5.0 mg/l is generally considered a safe lower limit. Within these constraints we can clearly see that artificial hypolimnion aeration greatly increased the "lebensraum" available to the rainbow trout (Figure 69). During early August 1969, 24% of the lake had adequate oxygen, but the temperature was too great. Forty-one percent had adequate temperature, but the oxygen was too low. Thirty-five percent had both adequate oxygen and temperature. During the same period 1970, over 97% of the lake had both adequate oxygen and temperature due to artificial hypolimnion aeration. If the aeration tower had operated as intended, the surface water would still be too warm, but in our case, the surface waters were apparently cooled slightly because of the faulty design and construction. In many lakes, especially in the American southwest, the portion of the lake with adequate oxygen and temperature approaches zero due to very high surface temperatures and hypolimnetic oxygen depletion within and below the metalimnion (Fast, 1968; Fast and St. Amant, in preparation). Many of these lakes are eutrophic and owe their richness in large part to the high nutrient content of their basins, watersheds and water sources. This high nutrient content causes plankton blooms, hypolimnetic oxygen depletion and many other conditions deleterious to water management. Because of water shortages, these lakes are managed intensively for

Figure 69. Hemlock Lake oxygen and temperature conditions for trout during August 1969 and August 1970. Adequate temperature is temperature less than 24°C, and adequate oxygen is values of 5 mg/l or more.


Adequate Temperature
Adequate Oxygen
Adequate Oxygen And Temperature
24%
35%
41%
97%
1969
1970
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
Distance From Aerator (m)

multiple uses. Many water managers have attempted to alleviate the deleterious eutrophic conditions by artificially destratifying their lakes with compressed air. Artificial destratification of eutrophic lakes is a useful fisheries management technique (Fast, 1968; 1971). It increases the habitat and food available to many fishes. It reduces the probability of oxygen depletion by algal decay and respiration. It is most widely used to improve domestic water quality. With continued complete mixing, it also increases the heat budget and eliminates the deep, cold hypolimnetic water. This water is generally anoxic. While artificial destratification eliminates this anoxia, it also greatly increases the bottom temperature. After continued destratification, the entire lake is about the same temperature as the surface before destratification began. These reservoirs, whether destratified or not, presently support year-round warmwater fisheries, but coldwater fisheries only when surface temperatures are less than 24°C. Development of such reservoirs for year-round coldwater fisheries will greatly increase their fisheries potential. High angler demand for trout coupled with the usual location of such reservoirs near populous areas would result in manyfold increases in angler patronage.

Presently, the only known method of creating suitable coldwater habitat in an eutrophic lake is by artificial hypolimnion aeration. This system of aeration can result in adequate oxvgen values throughout the lake without intolerable increases in hypolimnion temperatures. Oxygen can be added to the hypolimnion without mixing it with, or heating epilimnetic or metalimnetic water. This may be accomplished through modifications of my basic hypolimnion aerator design, or use of other designs.

Artificial destratification of oligotrophic lakes may result in the elimination of the coldwater species. The oxygen concentration may be little affected, but the bottom temperature will be greatly increased. Although destratification will not greatly affect water quality, it may be conducted to reduce evaporation rates. Annual evaporation may be reduced from 4 to 10% (Koberg, 1964; Koberg and Ford, 1965; and personal communication). From the fisheries standpoint, artificial destratification of oligotrophic lakes can be deleterious. An exception is when stratified surface temperatures normally are not limiting to the cold water biota. In this case destratification may increase fish food and trout production.

After artificial hypolimnion aeration is initiated, a system for stocking coldwater fish into the cold, aerated hypolimnion must be developed. Stocking the trout at the lake's surface, in the usual manner, will cause mortality due to thermal shock. Sharpe (1961) transported rainbow trout in plastic bags to the hypolimnion of a Tennessee reservoir. Some of these fish made short excursions towards the surface, but soon returned to the hypolimnion. Trout stocked at the surface were greatly distressed and disoriented; many died. A more appropriate method of stocking could be devised. A simple method would use a length of irrigation pipe extending from the shore, along the bottom into the hypolimnion. Water could be pumped from the hypolimnion through a separate hose and used to flush the fish into the hypolimnion. Fish could then be stocked directly into the pipe from a hatchery truck.

SECTION FOUR LAKE

Destratification System

The Section Four Lake artificial destratification system was very similar to the diffuse aerator described by Fast (1968). A 38 mm I.D. plastic pipe conducted air from the rim of the lake's basin to the deepest point in the lake (Figures 70 and 71). The distal 19 meters were perforated with 48 holes. The holes were 3.2 mm in diameter and located at 12 sites. Four holes were located at each site, positioned at 90° intervals around the pipe. The hole sites were unevenly distributed along the 19 meter section. From the distal end, they were positioned in meters as follows: 0.0, 0.6, 1.2, 2.5, 3.7, 4.9, 7.4, 9.8, 12.9, 16.0, and 19.0. The air line portion leading from the compressor to the shore was covered with soil to prevent damage by porcupines. Porcupines chewed the tires on the compressors and the plywood decks on the barges at both lakes, but were not a problem after we began aerating. The sound of the compressors apparently kept them away. The air line portion in the lake was anchored with several cement blocks. These were tied directly to the air line.

Figure 70. Cross-sectional view of Section Four diffuse aeration system. The air was released from the last 10 meters of pipe, situated near the deepest point in the lake.

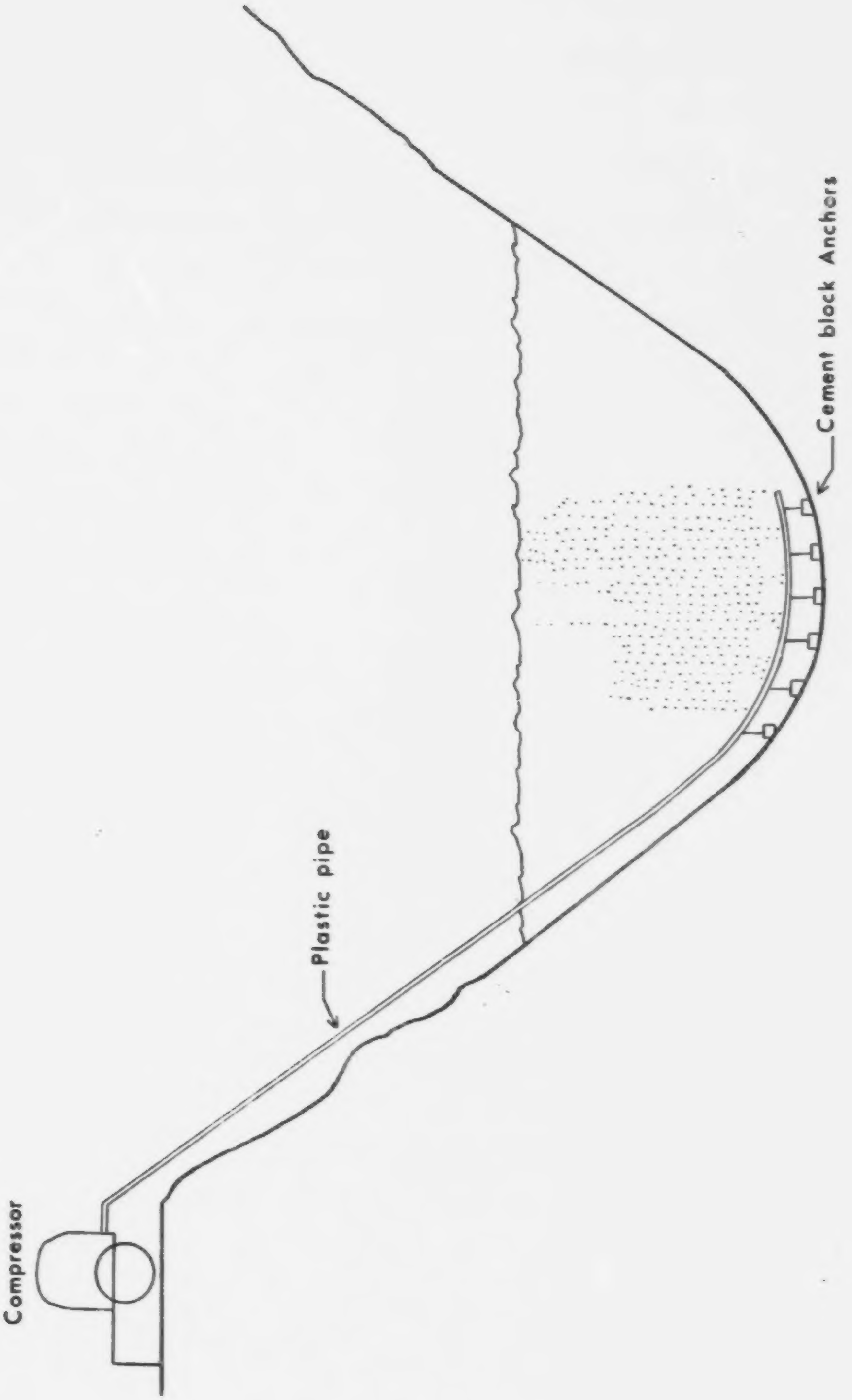

Cement block Anchors
Plastic pipe
Compressor

Figure 71. View of Section Four Lake taken from the basin rim. Rising air and water is seen near the center of the lake. (Photo by author.)

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Compressor. We used a Jenbach JW78 diesel compressor. It was always run at maximum speed and delivered 78 cfm at 100 psi. It was fueled with five gallons of diesel each day and ran about five hours. On a few occasions it was fueled two or three times on a given day.

Compressor Operation. Aeration began June 16, 1970. Destratification was rapid but the bottom 3-4 meters were not being circulated. Two factors contributed to this situation: (1) The end of the air line was not adequately anchored; the air line bowed up and was four to six meters off the bottom. Most of the air escaped at the top of the bow due to reduced hydrostatic pressure, and (2) The air was not released over the deepest point in the lake due to the air line bow. Knoppert et al. (1970) produced a similar result by purposely positioning their air line at an intermediate depth. Their lake was totally mixed at depth shallower than their air release, but not deeper.

On June 20, 1970, I added additional anchors to the air line using SCUBA. Thereafter the air release was more uniform along the perforated section, and extended to the deepest point in the lake. The entire lake was then circulated.

RESULTS

Physical-Chemical Parameters

Temperature and Oxygen. Section Four Lake stratified normally during 1969. By early June, a thermal gradient extended from 3.5 to 12 meters (Figure 72). Strictly speaking (i.e., a thermal gradient of 1°C/m) the metalimnion extended from 3.5 to 7.5 meters. This definition seems somewhat arbitrary in this case since the gradient decreased uniformly with depth. Although the gradient between 7.5 and 12 meters was less than 1°C, it appears to represent stable stratification. Temperatures ranged from 7°C at the bottom to 16°C at the surface. During this same period oxygen concentrations were 8.7 mg/l at the surface and 9.5 mg/l at the bottom (Figure 73). Metalimnion oxygen maxima occurred during the summer 1969, but were not as pronounced as in Hemlock Lake (Figure 36). As the summer progressed, the thermal gradient region increased in depth. By late August it extended from 5.0 to 14.5 meters. The isotherms are nearly parallel during the entire summer. Maximum surface temperatures of over 23°C were observed during mid-July and again during mid-August. These surface temperature maxima coincide with maxima for Hemlock Lake. Minimum bottom

Figure 72. Section Four isotherms during the summer, 1969, before aeration began. Isotherms are in °C.

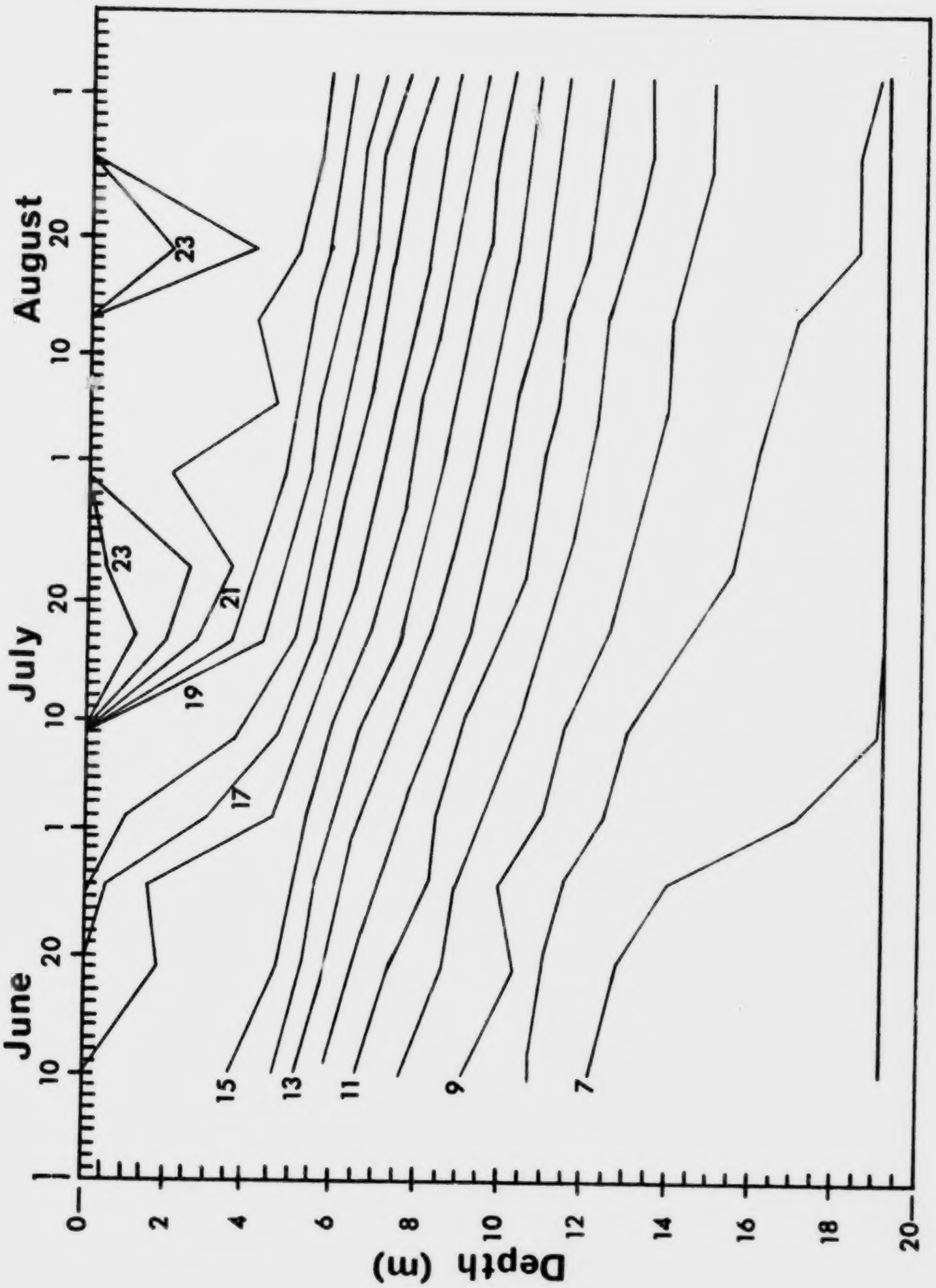
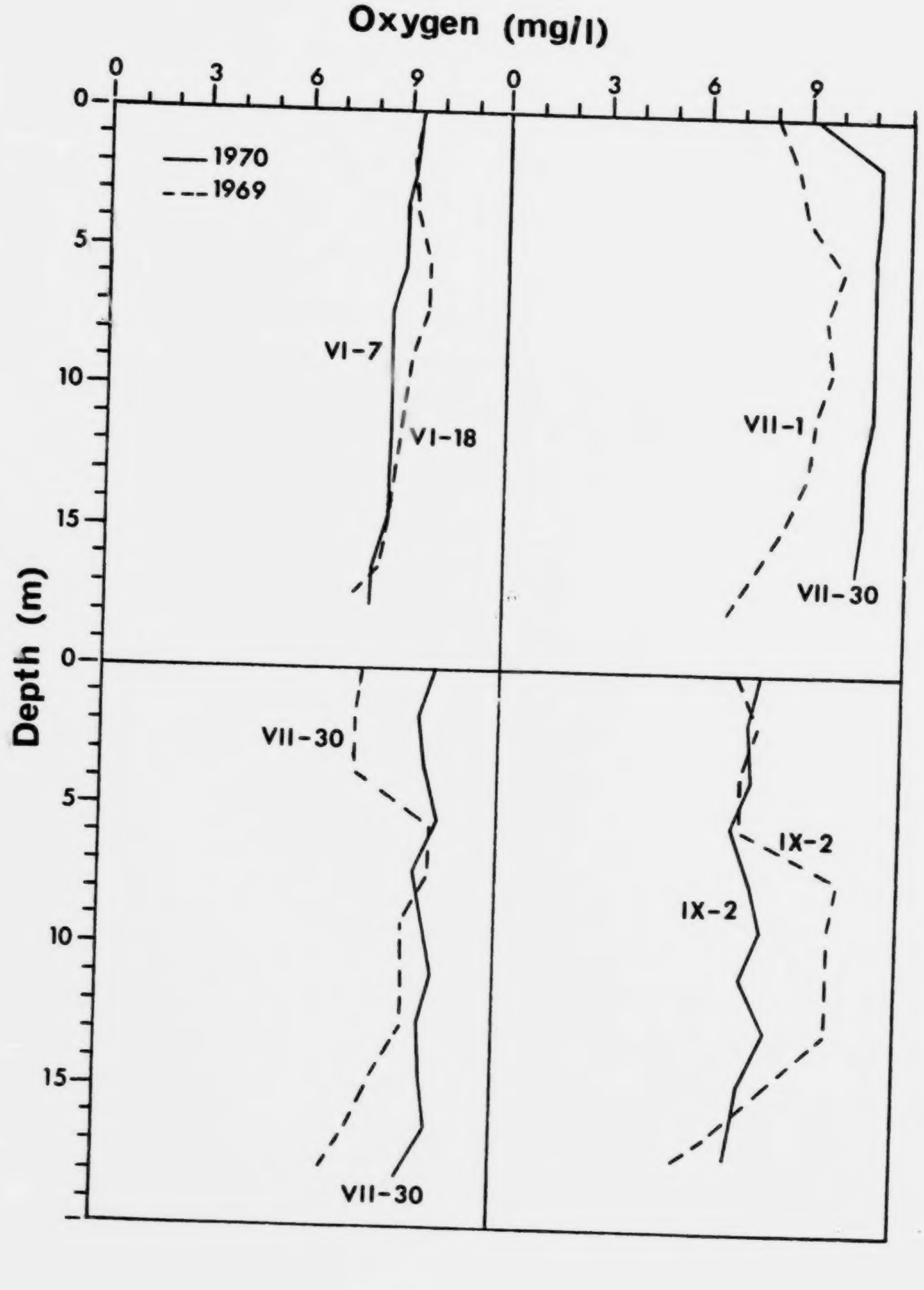

June
July
August
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
15
13
11
9
7
17
19
21
23
23

Figure 73. Section Four selected oxygen profiles during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

280



Oxygen (mg/l)
0
3
6
9
0
3
6
9
Depth (m)
0
5
10
15
0
5
10
15
— 1970
- - - 1969
VI-7
VI-18
VII-1
VII-30
VII-30
VII-30
IX-2
IX-2

temperatures were stable, but increased about 1°C during the summer 1969 (Figure 74). Average and surface oxygen concentrations varied considerably during the summer 1969, but were always above 6.0 mg/l (Figure 75). Bottom oxygen concentrations decreased during the summer 1969 but were always above 4.0 mg/l.

Before aeration began during June 1970, the thermal regime was similar to that of June 1969 (Figure 75). Temperatures ranged from 21°C at the surface to 5.5°C at the bottom. The thermal profiles were similar although the surface was warmer, and the bottom slightly cooler during 1970. Oxygen values were likewise very similar to 1969 values. Oxygen concentrations ranged from 8.0 mg/l at the bottom to 9.2 mg/l at the surface (Figures 73 and 74).

Artificial air injection began June 16, 1970 and caused immediate and significant changes in the temperature regime (Figures 76 and 77). After four days of aeration the surface temperature decreased from 21°C to 14°C and much of the lake was isothermal. By July 1st, the lake was nearly isothermal at 16°C except for the upper meter which approached 25°C. By July 10th the entire lake was isothermal at 18.5°C. The average temperature increased gradually and reached a 23.3°C maximum, compared to a 19.7°C maximum average during 1969. Surface temperatures were not greatly altered by artificial destratification, but bottom temperatures reached a 23.3°C maximum during 1970, compared to 8°C during 1969. With

Figure 74. Section Four maximum, minimum and average temperatures (^{O}C) during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

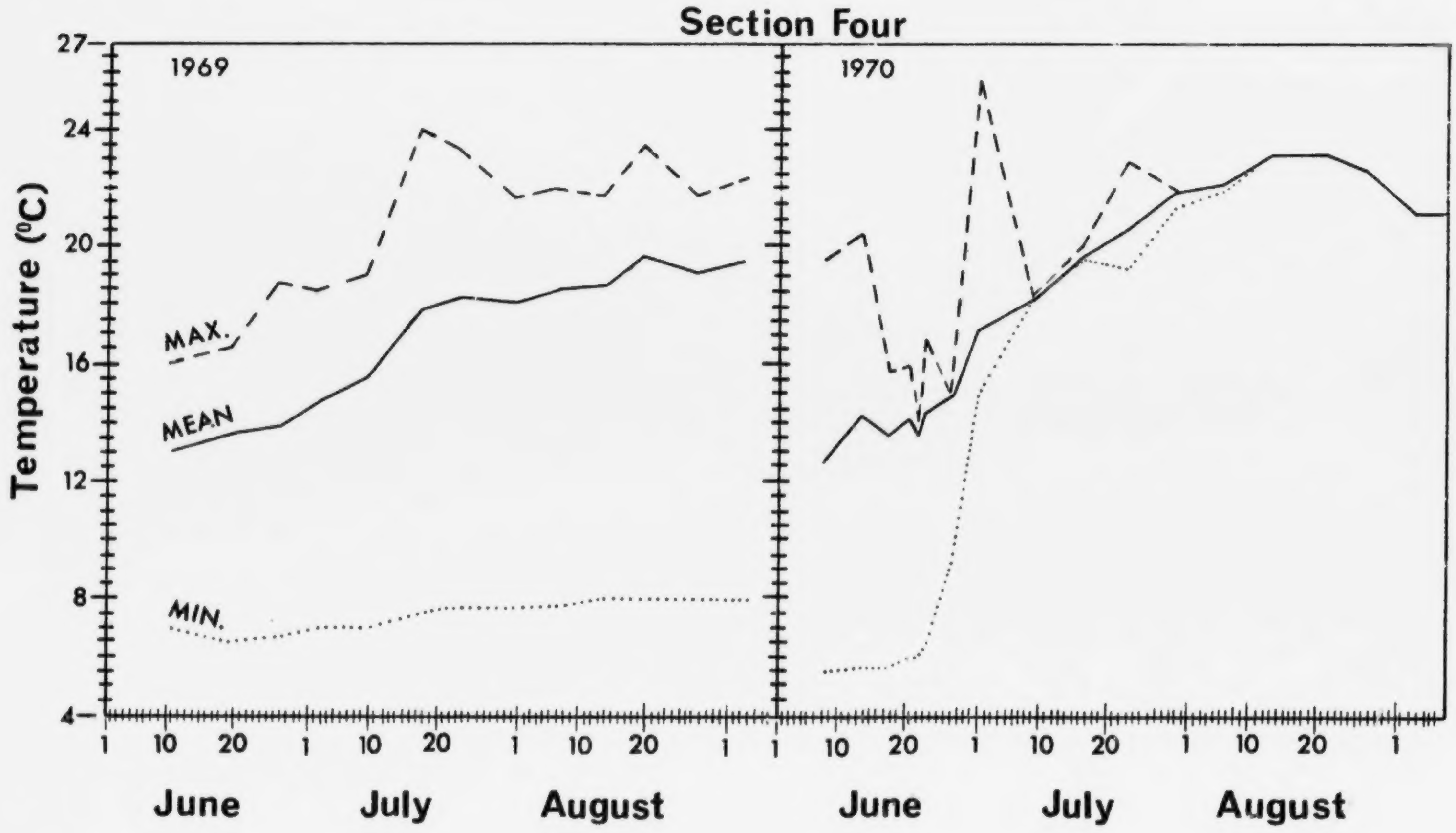

Section Four
Temperature (⁰C)
27
24
20
16
12
8
4
1969
1970
MAX.
MEAN
MIN.
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 75. Section Four top, bottom and average oxygen concentrations during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

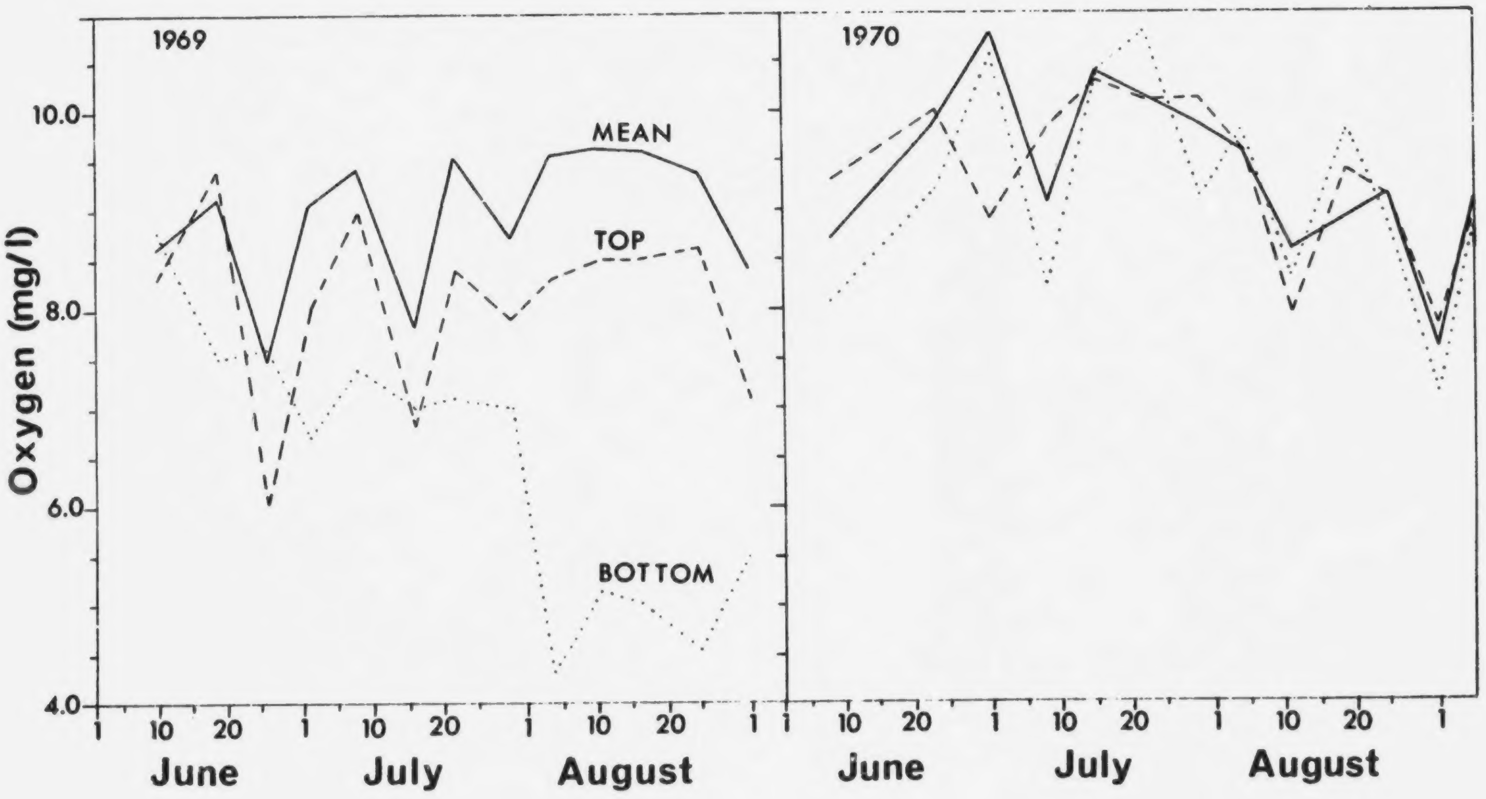

1969
1970
Oxygen (mg/l)
10.0
8.0
6.0
4.0
MEAN
TOP
BOTTOM
1
10
20
1
10
20
1
10
20
1
June
July
August
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 76. Section Four selected temperature profiles during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

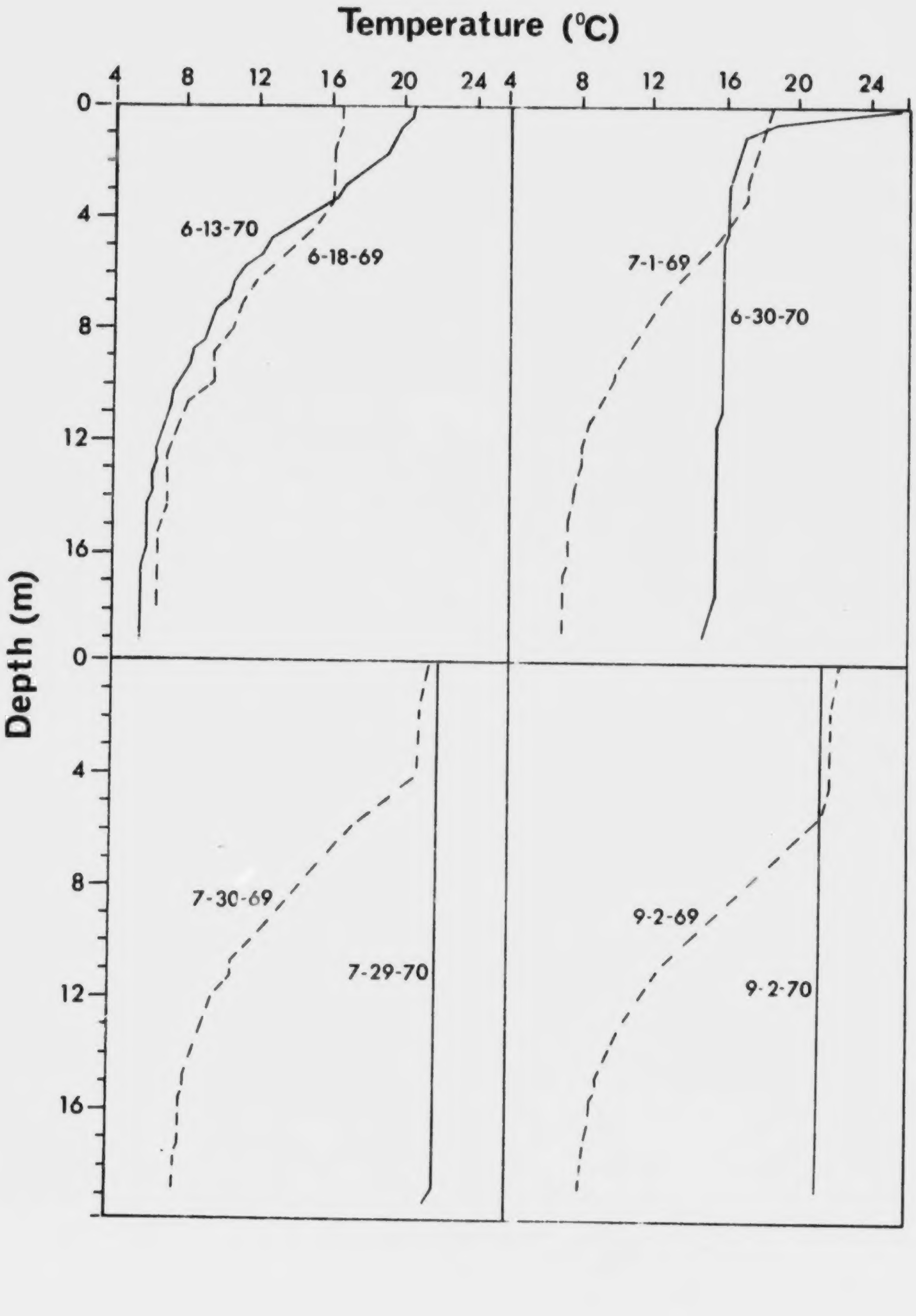
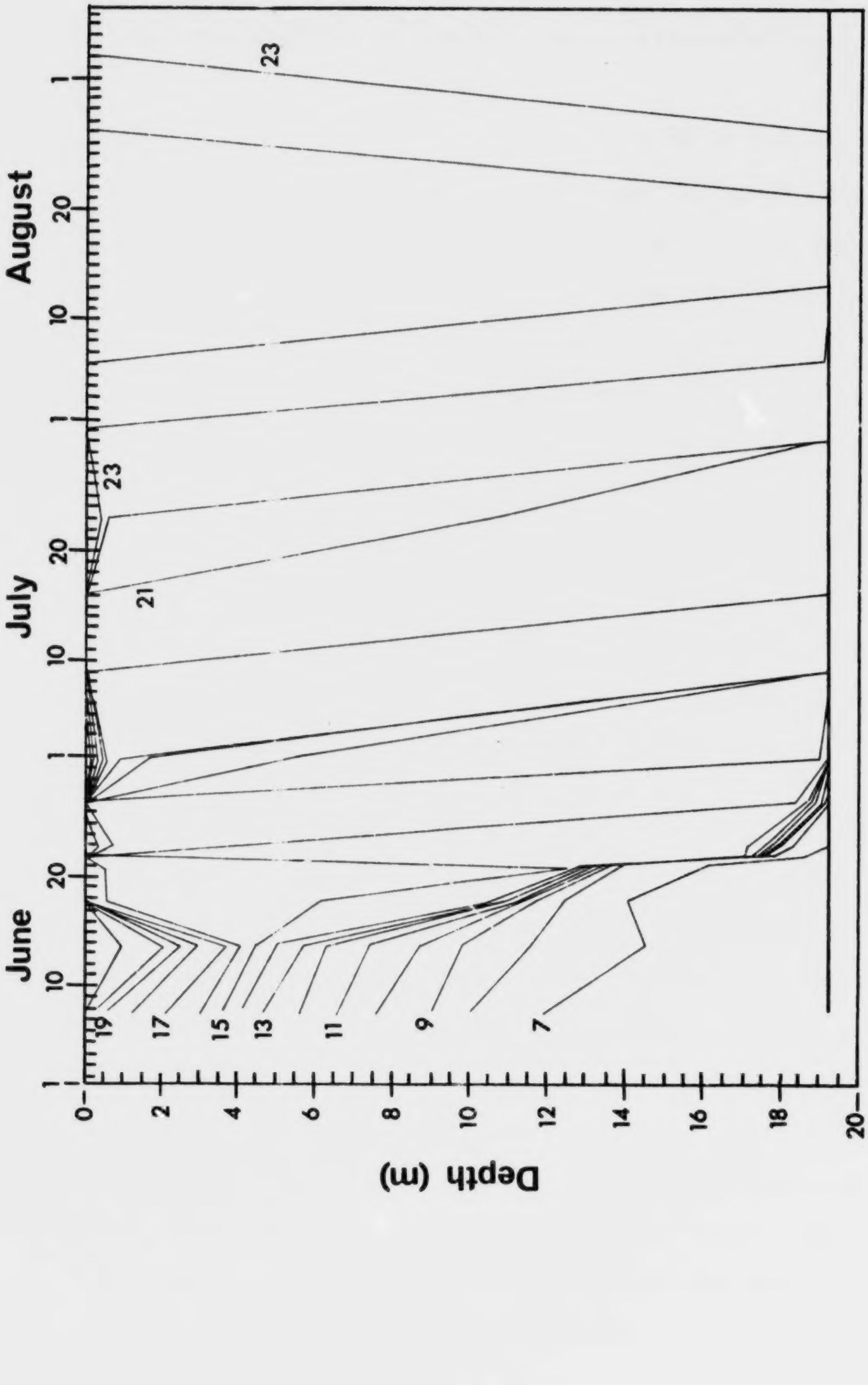

Temperature (°C)
4
8
12
16
20
24
4
8
12
16
20
24
Depth (m)
0
4
8
12
16
0
4
8
12
16
6-13-70
6-18-69
7-1-69
6-30-70
7-30-69
7-29-70
9-2-69
9-2-70

Figure 77. Section Four isotherms during the summer 1970. Aeration occurred between June 16th and September 7th. Isotherms are in °C.


Depth (m)
0
2
4
6
8
10
12
14
16
18
20
June
July
August
1
10
20
1
10
20
1
10
20
1
19
17
15
13
11
9
7
21
23
23

continuous aeration, the entire lake became about as warm as the surface waters were during stratified periods (Figure 74).

Thermal stability was 7×10^8 kg-m on June 10, 1970, compared to 5×10^8 kg-m the previous year on this date (Figure 78). After 4 days of artificial aeration stability neared zero. It was always near zero after July 29, 1970, whereas it reached a maximum value of over 12×10^8 kg-m on August 20, 1969. These changes reflect the degree of stratification and indicate the lake was nearly isothermal during most of 1970.

Oxygen values were more uniform after aeration began. Surface values were about the same, but bottom values were always above 7.0 mg/l compared to 4.5 mg/l during 1969. Oxygen maxima at intermediate depths were not present during 1970, and the oxygen profiles were nearly vertical.

pH, Alkalinity and Conductivity. During 1969, pH values were variable, but always above 7.5 (Figure 79). Bottom values were always lower than surface values, but on July 14, 1969 the average pH was higher than the surface pH. The average pH increased from 7.7 on July 14, 1969 to 8.0 by September 1969. After aeration began the pH was very uniform throughout the lake and nearly constant at 7.9 throughout the summer 1970.

Alkalinity was quite consistent during 1969. Bottom values averaged about 190 mg/l and surface values about 170 mg/l (Figure 80). After aeration began alkalinity was nearly

Figure 78. Section Four stability values during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

292

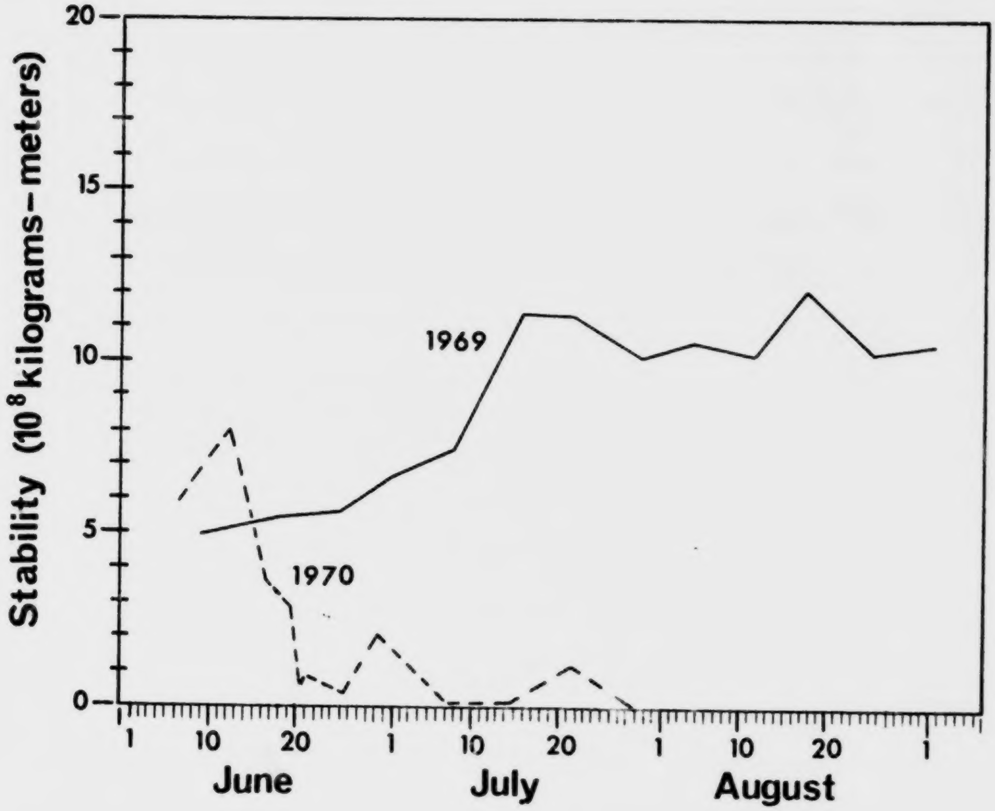

Stability (10^8 kilograms-meters)
20
15
10
5
0
1969
1970
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 79. Section Four's bottom, top and average pH values during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

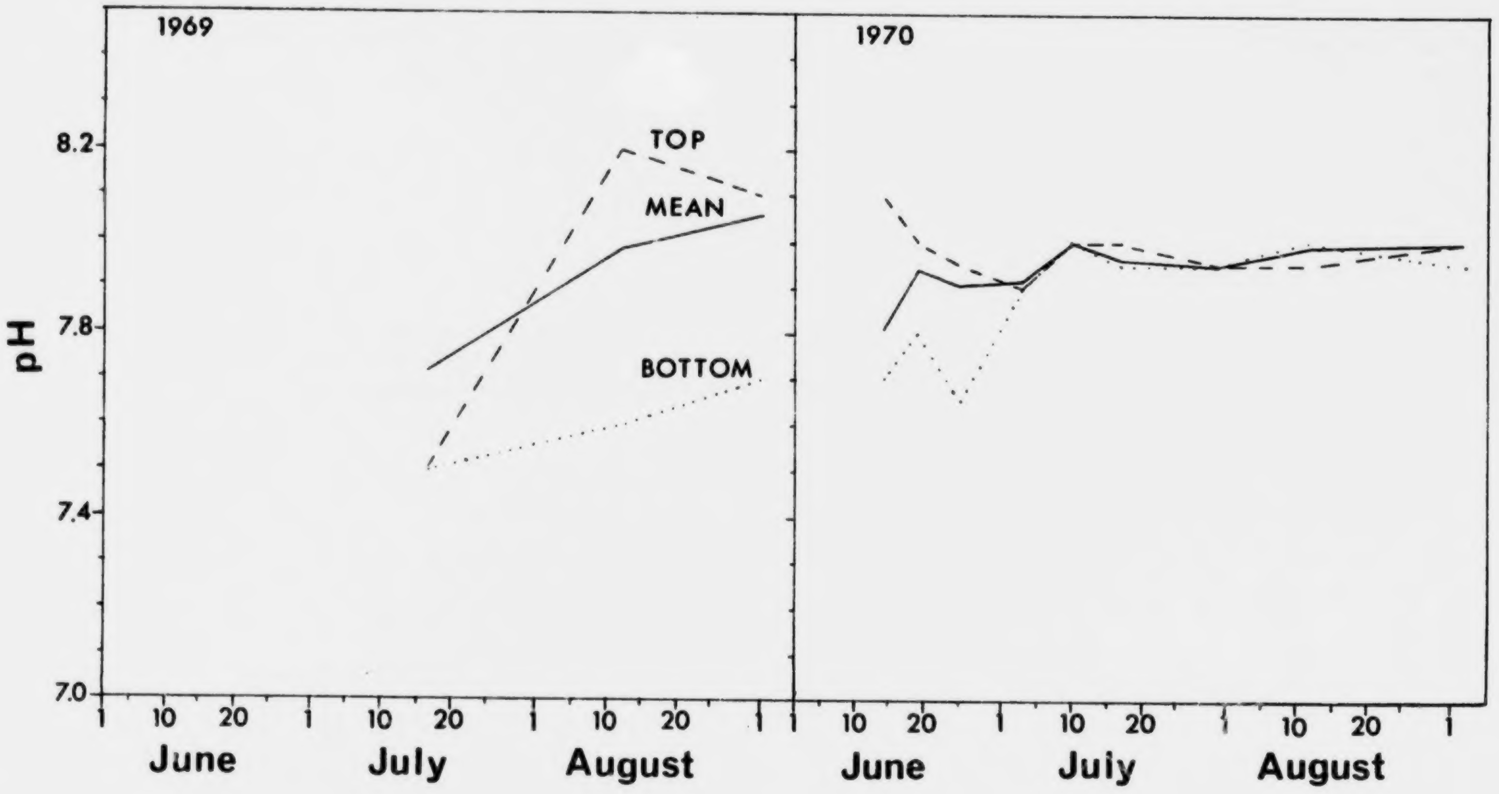
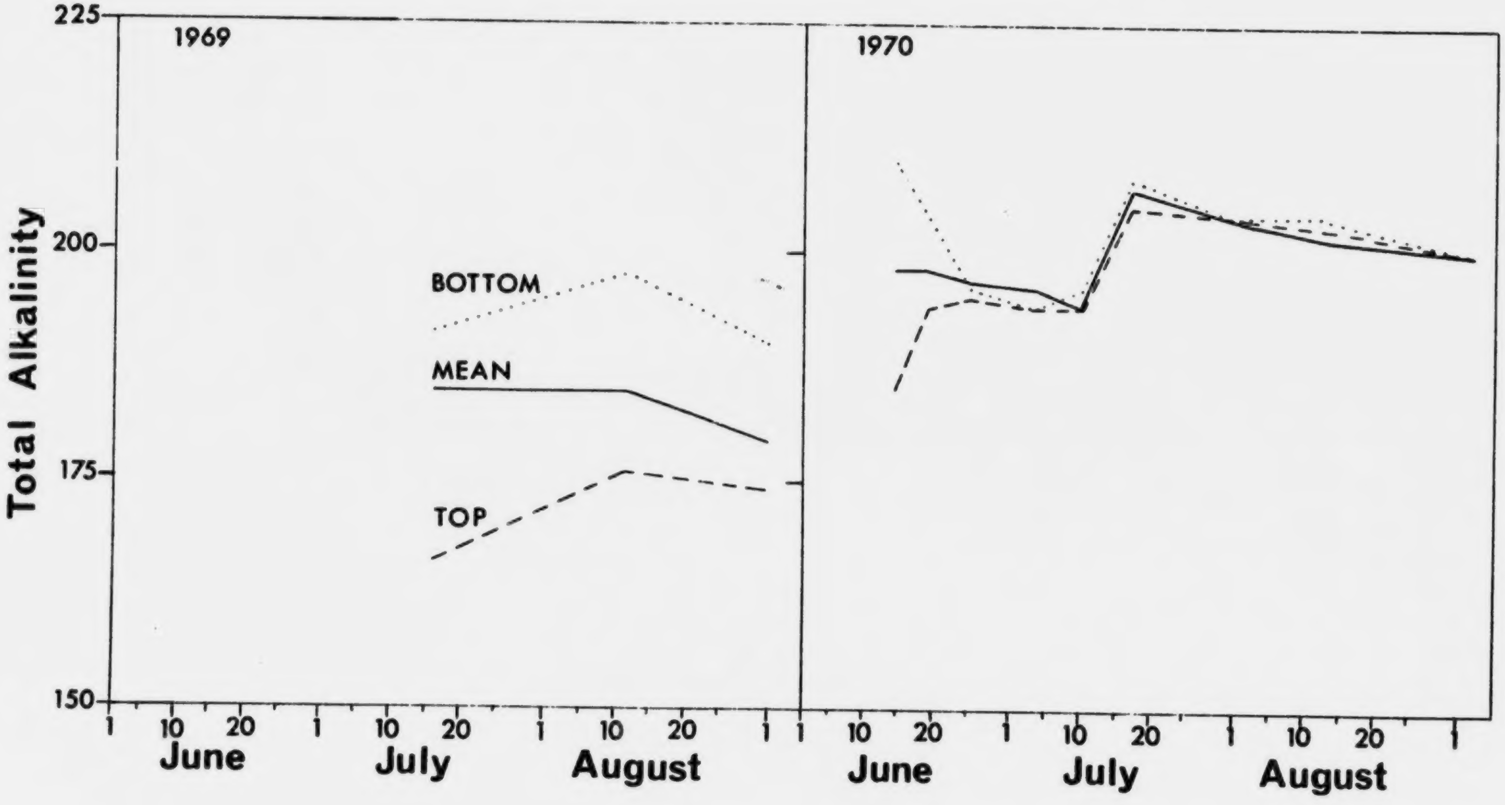

1969
1970
pH
8.2
7.8
7.4
7.0
TOP
MEAN
BOTTOM
1
10
20
1
10
20
1
10
20
1
June
July
August
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 80. Section Four bottom, top and average alkalinity values during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.


Total Alkalinity
225
200
175
150
1969
1970
BOTTOM
MEAN
TOP
1
10
20
1
10
20
1
10
20
1
June
July
August

296

constant at all depths. Average alkalinity reached a maximum of over 200 mg/l during 1970 compared to a 185 mg/l maximum during 1969.

Conductivity followed the same general pattern as alkalinity during 1969 (Figure 81). Surface values averaged about 350 micromhos and bottom values about 410 micromhos. After aeration began, conductivity was somewhat erratic until mid-July. It was nearly uniform on any given date after aeration, but average values ranged between 365 and 415 micromhos during 1970, compared to 370 to 385 micromhos during 1969.

Phosphorus. Phosphorus concentrations were measured only during 1969. On July 22, 1969 total phosphorus ranged from 0.002 to 0.062 mg/l (Table 7). Its distribution is erratic. Total dissolved phosphorus was more uniform, but near the limit of resolution for the analytical method used. It ranged from 0.002 to 0.010 mg/l.

Ca, Na, K, Mg, DOM and POM. These constituents were measured only during the summer 1970. Average calcium decreased from 56.0 mg/l during mid-June to 52.6 mg/l by August (Table A-12). Calcium, like the other constituents, does not exhibit much vertical variability, even before aeration began. Average sodium and potassium concentrations were nearly constant all summer. Average magnesium concentrations varied from 16.0 mg/l to 9.8 mg/l. Dissolved organic matter and particulate

Figure 81. Section Four bottom, top and average conductivity values during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.

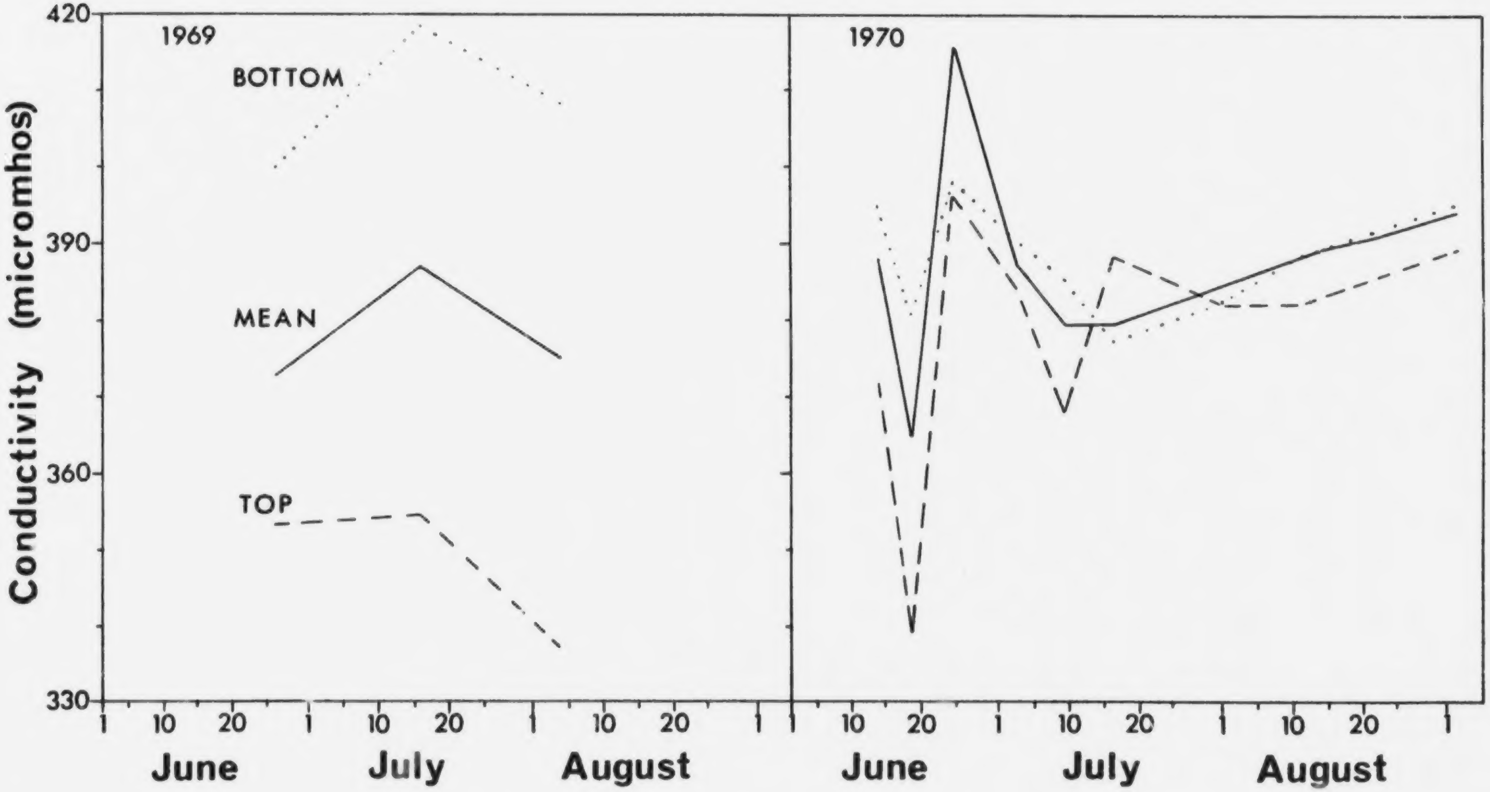

Conductivity (micromhos)
420
390
360
330
1969
BOTTOM
MEAN
TOP
1970
1
10
20
June
July
August

Table 7. Section Four Lake total phosphorus and total dissolved phosphorus collected July 22, 1969. Two water samples were collected from each depth interval.

	Total Phosphorus (mg/l)			Total Dissolved Phosphorus (mg/l)		
Depth	x_1	x_2	Mean	x_1	x_2	Mean
0.0	0.002	0.017	0.010	0.002	0.017	0.010
2.8	0.003	0.003	0.003	0.003	0.003	0.003
5.6	0.003	0.003	0.003	0.002	0.002	0.002
8.3	0.025	0.002	0.014	0.002	0.002	0.002
11.0	0.025	0.025	0.025	0.002	0.001	0.002
13.7	0.003	0.002	0.002	0.003	0.002	0.002
16.5	0.100	0.025	0.062	0.003	0.002	0.002
17.8	0.025	0.000	0.012	0.002	0.002	0.002

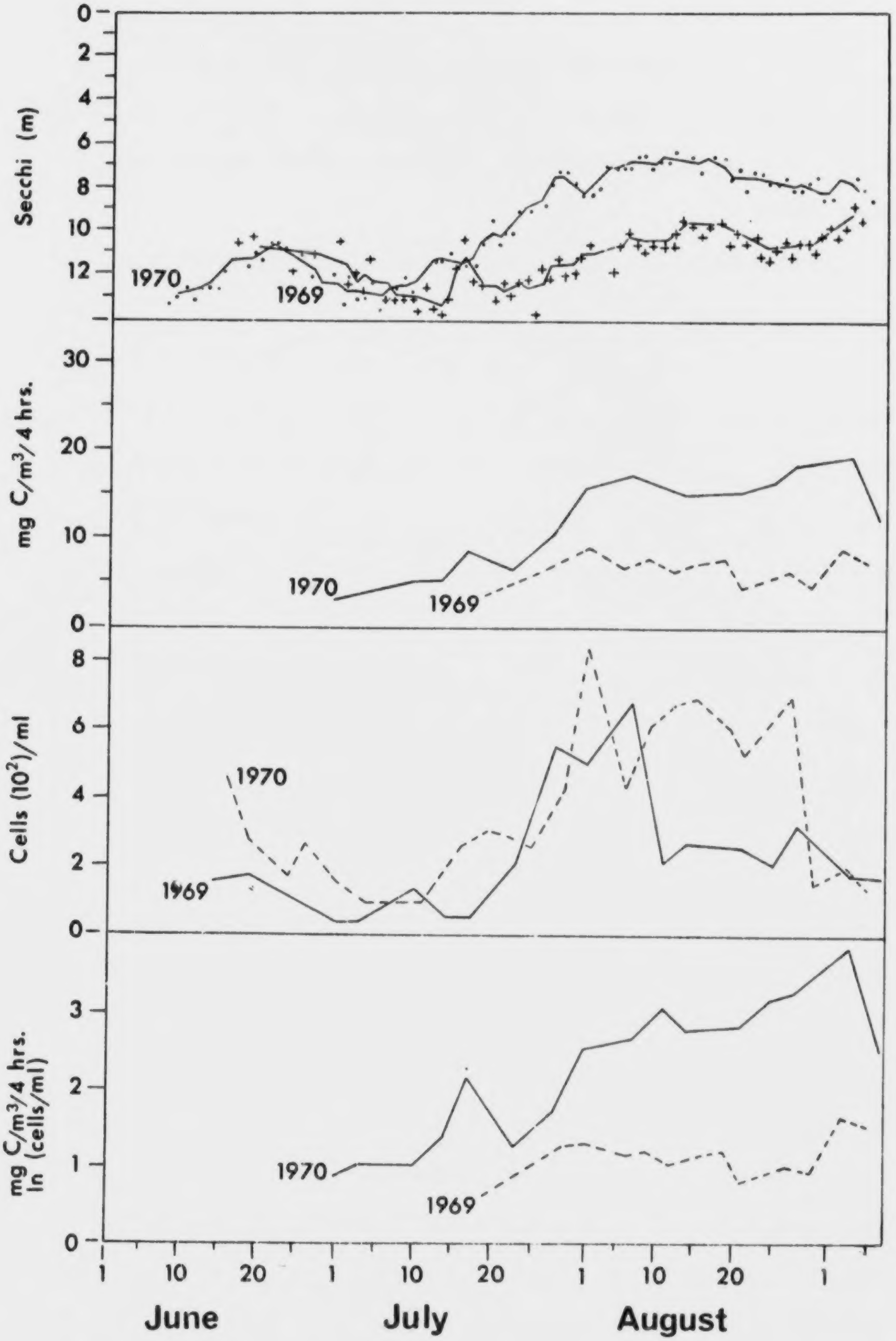
organic matter were most variable. Average DOM ranged between 2.74 mg/l to 6.18 mg/l, whereas DOM ranged between 117.1 mg/l to 436.2 mg/l.

Primary Production

Section Four appears very unproductive. Phytoplankton and attached algal densities are sparse. Secchi disc readings typically exceed 10 meters. *Chara* may be the main source of primary production since dense beds extend over as much as 10% of the lake's bottom. These plants were most abundant below 5 meters and extended to maximum depth both years. No estimates of the abundance or production rates were made because of the obvious technical problems involved. Instead, I concentrated on the phytoplankton and periphyton in hopes that relative changes in these two components would represent relative changes in the lake's primary production as a whole.

Phytoplankton. Phytoplankton standing crop and production rates were relatively low both years. Standing crop was about one-tenth that found in Hemlock Lake, and production ranged between one-fifth and one-thirtieth of Hemlock's. Primary production potential during July and August 1969 was fairly constant at 6 mg/m^3/4 hrs. (Figure 82). Surface standing crop averaged about 200 cells/ml during June and early July, but increased to about 600 cells/ml during August 1970. Secchi measurements reflect this change by decreasing from about 12 m to 10 m.

Figure 82. Section Four secchi disc transparencies, surface primary production potentials, surface phytoplankton densities and surface production efficiencies during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970.


Secchi (m)
0
2
4
6
8
10
12
1970
1969
mg C/m³/4 hrs.
30
20
10
0
1970
1969
Cells (10²)/ml
8
6
4
2
0
1970
1969
mg C/m³/4 hrs.
ln (cells/ml)
3
2
1
0
1970
1969
1
10
20
1
10
20
1
10
20
1
June
July
August

Artificial destratification during 1970 resulted in increased primary production potentials. Potentials during August 1970 were about three times as great as during August 1969.

Phytoplankton standing crops did not reflect the increases in production potential. On the contrary, average 1970 standing crops were less than 1969. Phytoplankton standing crops follow a similar pattern during June and July both years. Concentrations increased from 200 cells/ml during June 1970 to a maximum of over 600 cells/ml during the first week of August. A sharp reduction back to 200 cells/ml followed. Secchi disc measurements responded somewhat differently during 1970. Secchi measurements were about the same during June both years, but decreased to 6 meters by August 1970, compared to 10 meters during August 1969. This greater decrease occurred during 1970 even though surface phytoplankton densities were somewhat less than during 1969. Furthermore, Secchi measurements showed only a slight increase following the phytoplankton population decline during August 1970. The lower transparency during 1970 is probably due to suspension of detritus, sediments and other materials by the compressed-air-generated water currents. Brian Moss, who examined the samples, indicated that larger quantities of such materials were present in the 1970 plankton samples than in the 1969 samples.

Periphyton. Seventeen-day periphyton accumulation rates during June 1970 were less than during June 1969 (Figure 83). Thereafter, the 1970 values were always larger, with the possible exceptions of July 15th and August 30th. Average 17-day accumulation rates were about 0.004 gm/day during 1969 and about 0.007 gm/day during 1970.

Differences in 17-day periphyton accumulation rates were not reflected in total accumulation rates. Total accumulation rates were lower during June 1970, greater during early July 1970, but not different during late July and August. As with Hemlock, these total accumulations were almost linear during both summers. Accumulations increased from near 0.0 gm to about 0.5 gm both years.

Zoobenthos

Oligochaetes and Chironomids dominated the Section Four benthic fauna assemblage, exclusive of the crayfish. Together, they comprise about 93% of the numbers and 90% of the biomass during 1969 (Table 8 and Figure 84). During 1970, these percentages were 94 and 84 respectively. Ten other taxa comprised the remaining macrobenthic fauna. Chironomids were numerically more abundant than oligochaetes during 1969, but this situation was reversed during 1970. Oligochaetes had more biomass than any other taxa both years.

Zoobenthos biomass collected during 1969 totaled 11.9 gm and 7.93 mg during 1970 (Table 8). This is a 28% decrease

Figure 83. Section Four periphyton standing crops based on 17-day incubation periods and continuous incubation. The 95% confidence interval is shown about each average value. Aeration occurred between June 16 and September 7, 1970.

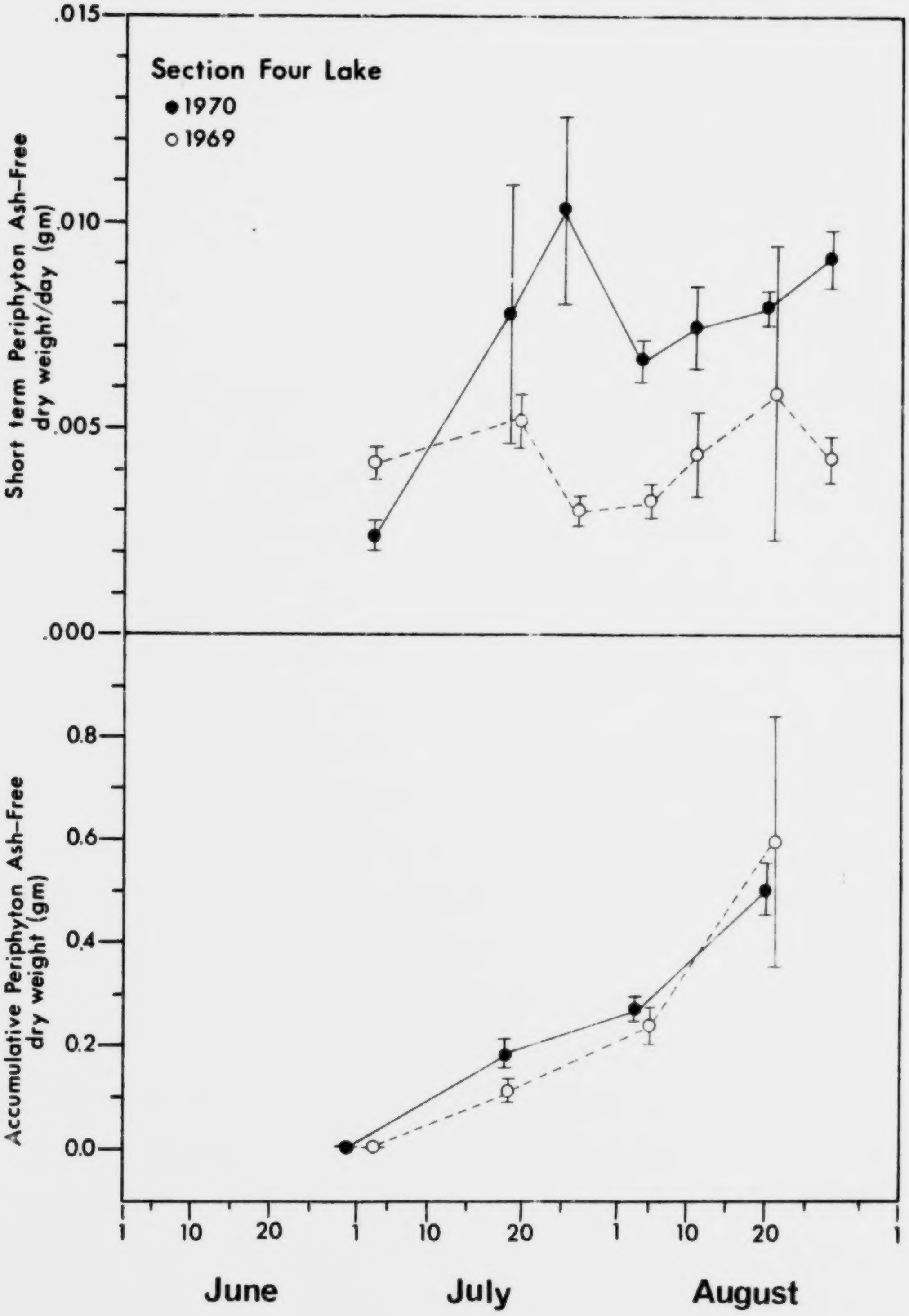

Section Four Lake
● 1970
○ 1969
Short term Periphyton Ash-Free dry weight/day (gm)
.015
.010
.005
.000
Accumulative Periphyton Ash-Free dry weight (gm)
0.8
0.6
0.4
0.2
0.0
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 84. Section Four zoobenthos percent composition during the summers 1969 and 1970. Percent of weight and percent of number are shown for each taxa. Total weights and total numbers collected each summer are also shown. Samples from dredge collections only.

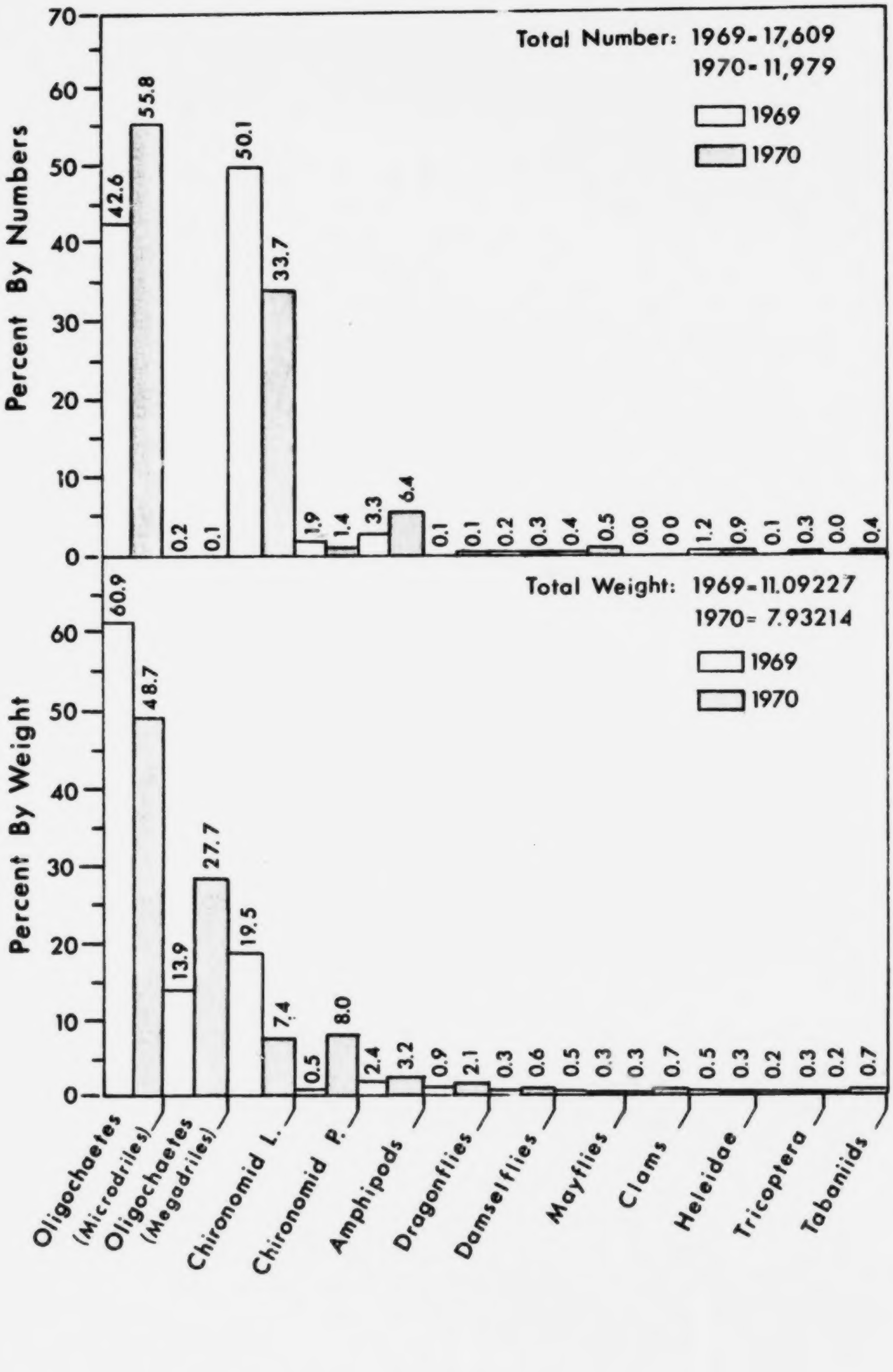

Percent By Numbers
70
60
50
40
30
20
10
0
Total Number: 1969- 17,609
1970- 11,979
1969
1970
42.6
55.8
0.2
0.1
50.1
33.7
1.9
1.4
3.3
6.4
0.1
0.1
0.2
0.3
0.4
0.5
0.0
0.0
1.2
0.9
0.1
0.3
0.0
0.4
Percent By Weight
60
50
40
30
20
10
0
Total Weight: 1969-11.09227
1970= 7.93214
1969
1970
60.9
48.7
13.9
27.7
19.5
7.4
0.5
8.0
2.4
3.2
0.9
2.1
0.3
0.6
0.5
0.3
0.3
0.7
0.5
0.3
0.2
0.3
0.2
0.7
Oligochaetes (Microdriles)
Oligochaetes (Megadriles)
Chironomid L.
Chironomid P.
Amphipods
Dragonflies
Damselflies
Mayflies
Clams
Heleidae
Tricoptera
Tabaniids

Table 8. Section Four Lake zoobenthos collected during the summers 1969 and 1970 with an Ekman dredge. 125 dredge samples were taken each summer. Wet weights are shown.

	Total Weight				Total Numbers				Number of Samples Found In		Mean Number of Individuals/gram	
	1969		1970		1969		1970					
	Grams	Percent	Grams	Percent	Number	Percent	Number	Percent	1969	1970	1969	1970
Oligochaetes (microdriles)	6.75189	60.9	3.86228	48.7	7,506	42.6	6,684	55.8	89	110	1,112	1,730
Oligochaetes (megadriles)	1.54189	13.9	2.19364	27.7	27	0.2	12	0.1	10	6	18	5
Chironomid L.	2.16182	19.5	0.59028	7.4	8,817	50.1	4,041	33.7	121	123	4,078	6,846
Chironomid P.	0.05490	0.5	0.63301	8.0	336	1.9	163	1.4	74	71	6,120	257
Amphipods	0.26445	2.4	0.25269	3.2	583	3.3	771	6.4	60	72	2,205	3,051
Dragonflies	0.09587	0.9	0.16457	2.1	11	0.1	13	0.1	7	10	115	79
Damselflies	0.03211	0.3	0.05024	0.6	31	0.2	32	0.3	18	23	965	636
Mayflies	0.05025	0.5	0.02288	0.3	62	0.4	61	0.5	35	34	1,234	2,666
Chaoborus spp. L.	0.00000	0.0	0.00075	0.0	0	0.0	1	0.0	0	1	--	1,333
Clams	0.03355	0.3	0.05209	0.7	1	0.0	8	0.1	1	7	30	154
Heleidae	0.05561	0.5	0.02733	0.3	203	1.2	102	0.9	54	45	3,650	3,752
Trichoptera	0.02433	0.2	0.02772	0.3	26	0.1	38	0.3	20	27	1,068	1,371
Tabaniid	0.02278	0.2	0.05348	0.7	5	0.0	45	0.4	4	18	219	341
Megaloptera	0.00280	0.0	0.00118	0.0	1	0.0	5	0.0	1	5	357	4,237
Total	11.09227	100.0	7.93214	100.0	17,609.	100.0	11,976	100.0				

in total biomass during the summer of destratification. Total numbers collected decreased 32% during this period from 17,609 during 1969 to 11,976 during 1970. Decreases in oligochaetes (microdriles) and chironomid larvae account for most of this change. Interestingly, associated with the decreases in biomass and numbers during 1970, the average size of oligochaetes, Chironomid larvae, amphipods, mayflies, Trichoptera, tabaniids and megaloptera also decreased substantially. Many of the minor species became relatively more abundant following destratification (Table 8).

Jarl Hiltunen could identify only two oligochaete microdrile species from Section Four: Limnodrilus hoffmisteri and Ilyodrilus templetoni. L. hoffmeisteri was much more abundant in the samples from which the specific identifications were made. Several large oligochaete megadrile specimens were collected, but not identified. These specimens closely resembled the common earthworm, and were only found in a gravel outcropping at 10 to 15 meters depth. Hiltunen tentatively identified these as Lumbricidae.

Oligochaetes were very abundant both years at depths below 14 meters (Figures 85 and 86). Their average depth for both numbers and biomass always averaged between 15 and 16 meters. There appears to be a slightly greater concentration of worms, especially small individuals, in shallow water after early July 1970 compared to 1969. Thermal stratification during 1969 may have led to their migration

Figure 85. Section Four oligochaete (microdriles) depth distribution as percent of numbers during the summers 1969 and 1970. Shaded histograms represent aerated periods.

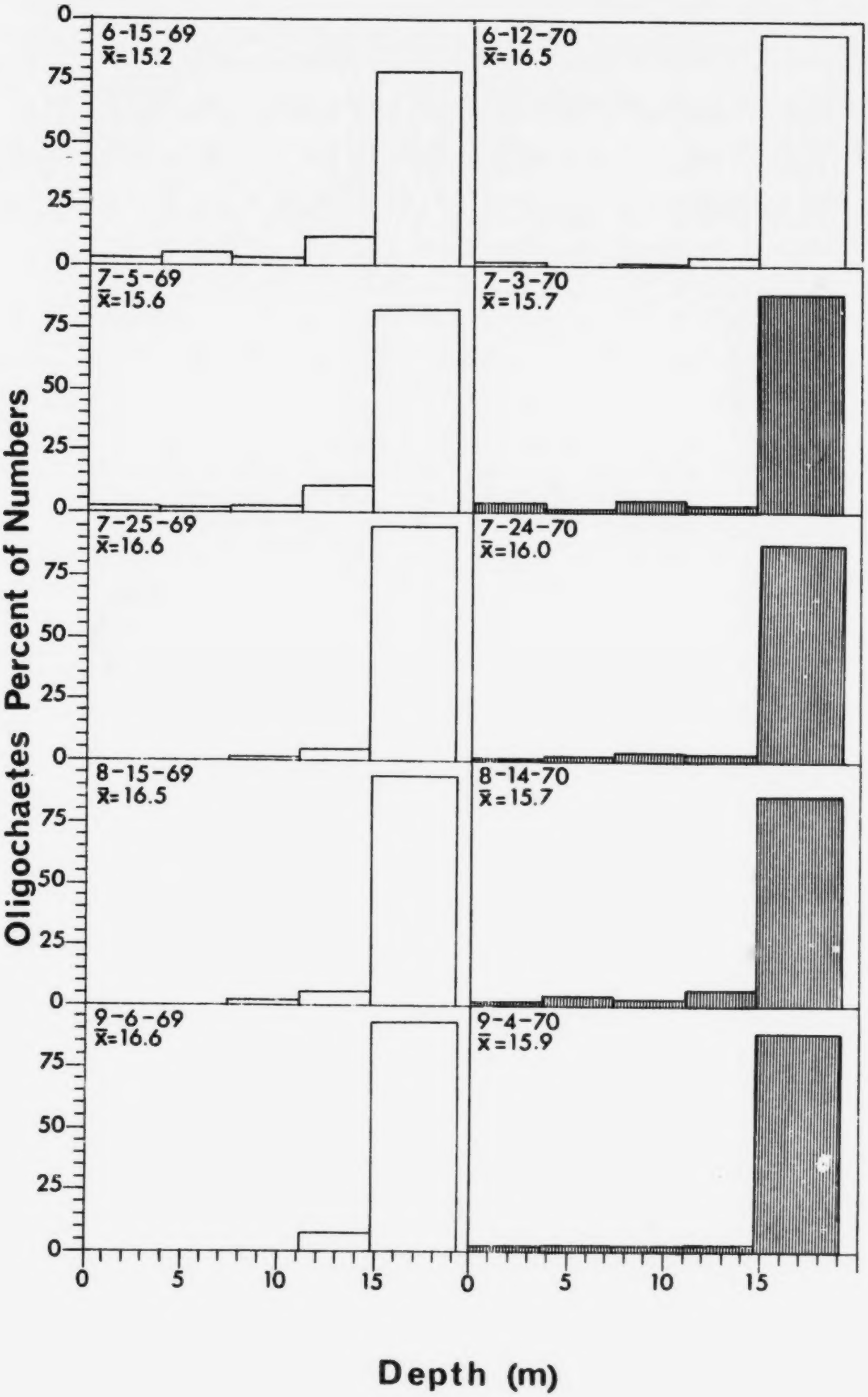
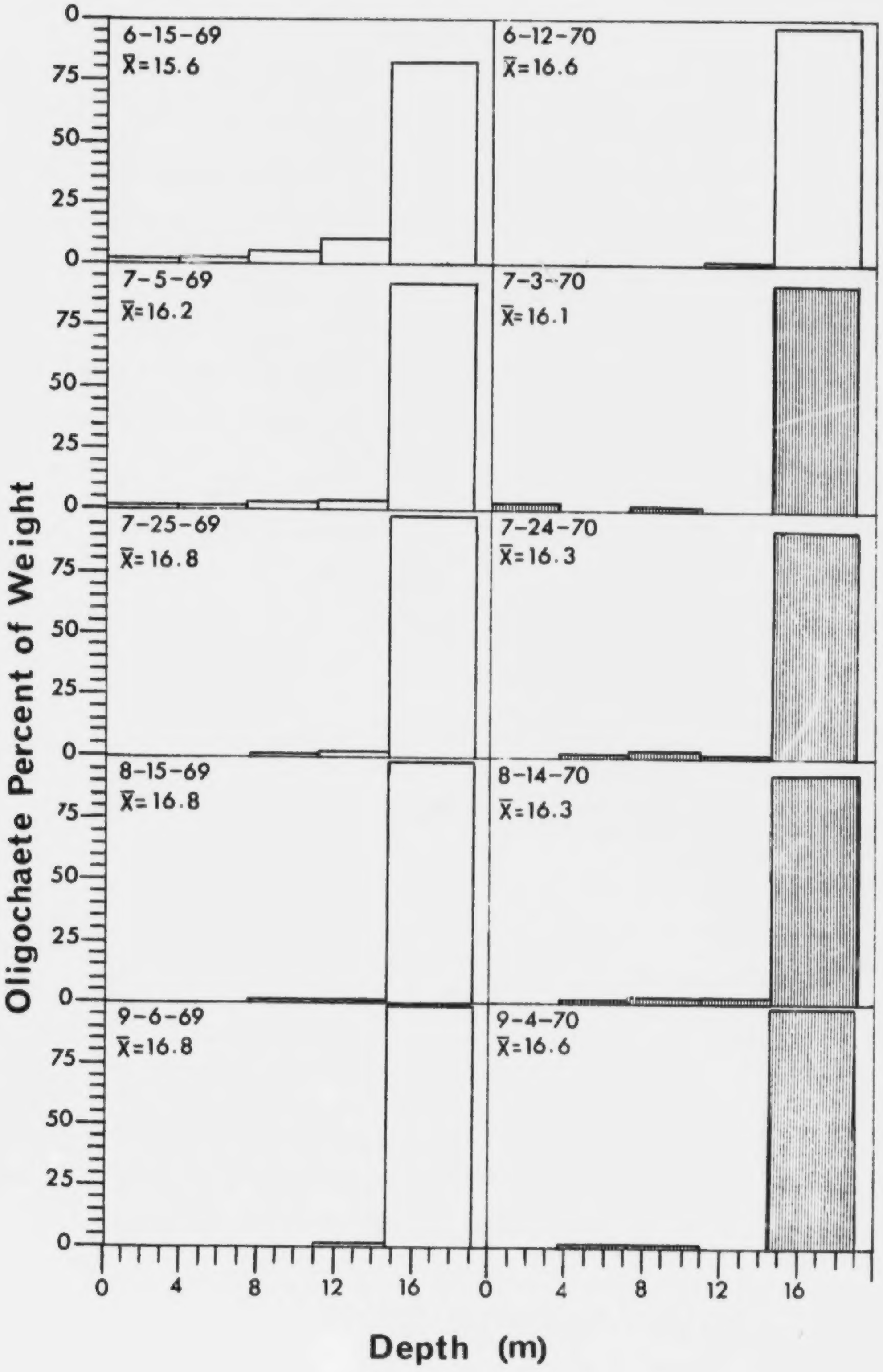

6-15-69
x̄=15.2
6-12-70
x̄=16.5
7-5-69
x̄=15.6
7-3-70
x̄=15.7
7-25-69
x̄=16.6
7-24-70
x̄=16.0
8-15-69
x̄=16.5
8-14-70
x̄=15.7
9-6-69
x̄=16.6
9-4-70
x̄=15.9
Oligochaetes Percent of Numbers
0
25
50
75
0
5
10
15
Depth (m)

Figure 86. Section Four oligochaete (microdriles) depth distribution as percent of wet weight during the summers 1969 and 1970. Shaded histograms represent aerated periods.


6-15-69
X̄=15.6
6-12-70
X̄=16.6
7-5-69
X̄=16.2
7-3-70
X̄=16.1
7-25-69
X̄=16.8
7-24-70
X̄=16.3
8-15-69
X̄=16.8
8-14-70
X̄=16.3
9-6-69
X̄=16.8
9-4-70
X̄=16.6
0
25
50
75
Oligochaete Percent of Weight
0
4
8
12
16
Depth (m)

into deeper water as the epilimnion warmed. The June 15, 1969 and July 15, 1969 samples contain some worms at all depths, but on July 25th and thereafter none were collected above 7 meters. When the lake was completely mixed after mid-June 1970, their depth distribution during the entire summer resembles the June distribution.

Total oligochaete (microdriles) biomass during 1970 decreased 43% from the 1969 total, and total numbers decreased 11% during this period (Table 8). The indication is that this decrease occurred after aeration began during 1970 (Figure 87). Total estimated oligochaete numbers and biomass were greater during mid-June 1970 than during mid-June 1969, but the 1970 totals decreased after aeration began such that by mid-July 1970 and thereafter both numbers and biomass were less than the 1969 totals. Large variances obscure the significance of these trends, but intuitively I believe they represent the true population responses.

Oligochaete (microdrile) average size decreased during 1970 compared to 1969 (Table 8). They averaged 1,112 individuals per gram during 1969, but 1,730/gm during 1970.

D. R. Oliver identified more than 11 chironomid midges based on adult emergence (Table 9). Four species, *Lauterborniella*, *Procladius*, *Ablabesmyia mallochi* and *Clinotanypus thoracicus* accounted for 67% of the total emergence during 1969 and 77% during 1970. Unidentified adult Chironomidae accounted for 10% of the total emergence during 1969 and 13%

Figure 87. Section Four total estimated oligochaete number and biomass during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970.

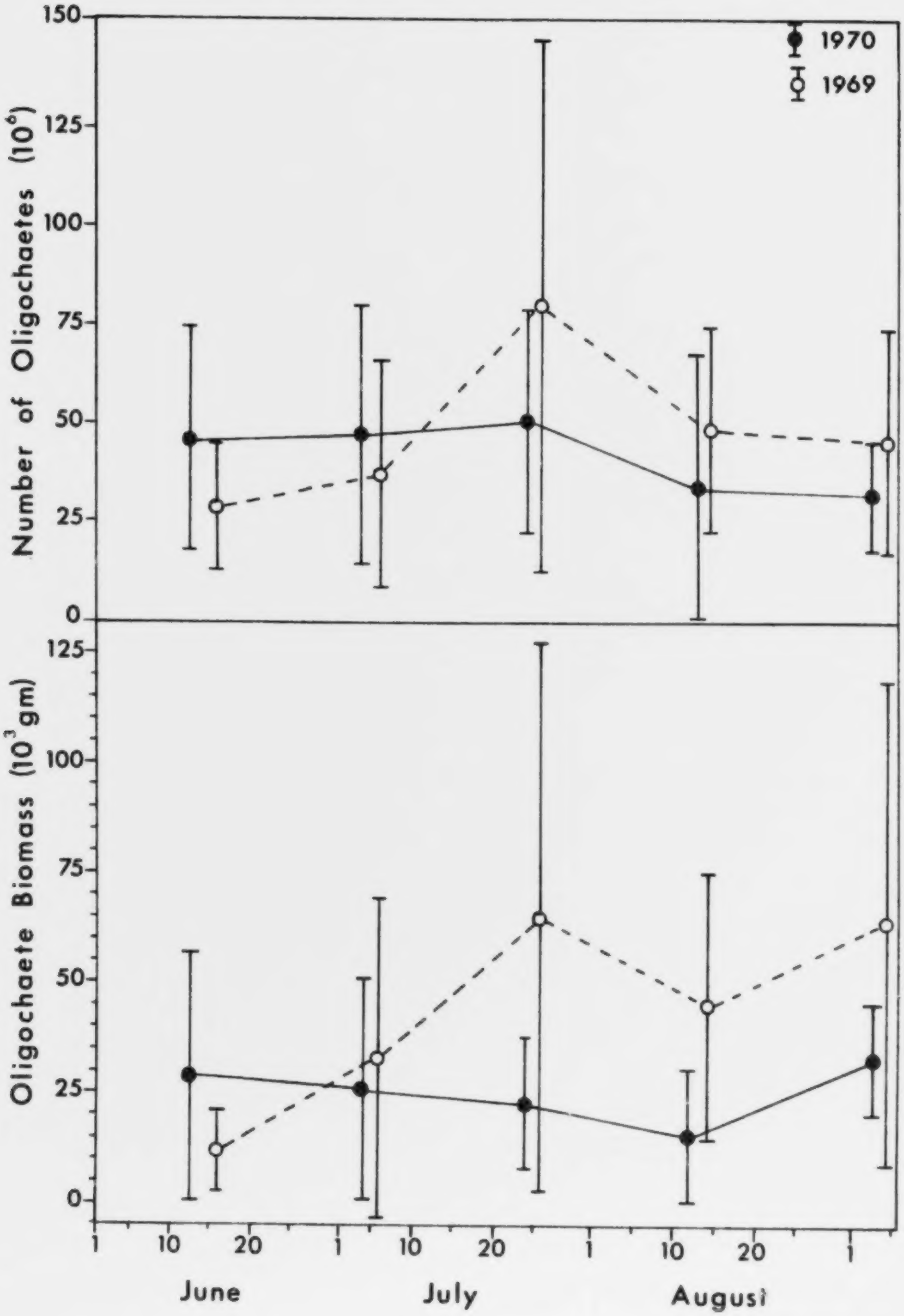

1970
1969
Number of Oligochaetes (10^6)
150
125
100
75
50
25
0
Oligochaete Biomass (10^3 gm)
125
100
75
50
25
0
1
10
20
1
10
20
1
10
20
1
June
July
August

Table 9 . Emergent midge adults collected from 600 samples during 1969, and 650 samples during 1970. All specimens are from Section Four Lake and were collected in emergent insect traps.

	1969				1970			
	Total Number	Percent of Total Number	No. of Samples	No. of Dates	Total Number	Percent of Total Number	No. of Samples	No. of Dates
Family - Chironomidae (Tendipidae)								
Subfamily - Chironominae (Tendipedinae)								
Lauterborniella spp.	128	16	51	32	96	13	42	32
Tanytarsus spp.	15	2	13	12	5	1	5	5
Polypedilum spp.	38	5	18	17	3	1	3	2
Chironomus spp.	13	2	11	8	22	3	14	11
Paratanytarsus spp.	2	1	2	2	5	1	5	5
Pagastiella spp.	3	1	2	1	0	0	0	0
Unidentified Chironomini (Tribe)	116	14	57	38	34	5	28	26
Subfamily - Pelopiinae (Tanypodinae)								
Procladius spp.	217	27	70	38	57	8	47	31
Ablabesmyia mallochi	140	17	73	41	307	42	130	53
Clinotanypus thoracicus	59	7	35	24	101	14	69	34
Subfamily - Hydrobaeninae								
Cricotopus spp.	2	1	2	2	0	0	0	0
Unidentified Adult Chironomidae	79	10	47	34	98	13	65	40
Totals		100	381		728	100	408	

during 1970. These adults included *Pseudochironomus netta*, *Endochironomus*, *Tanypus*, *Dicrotendipes fumidus*, *Cryptochironomus fulvus*, *Ablabesmyia monlis*, *Procladius bellus* and possibly other species. We had some problems of identification, and added our counts to the "unidentified" category when there was doubt as to the true identity.

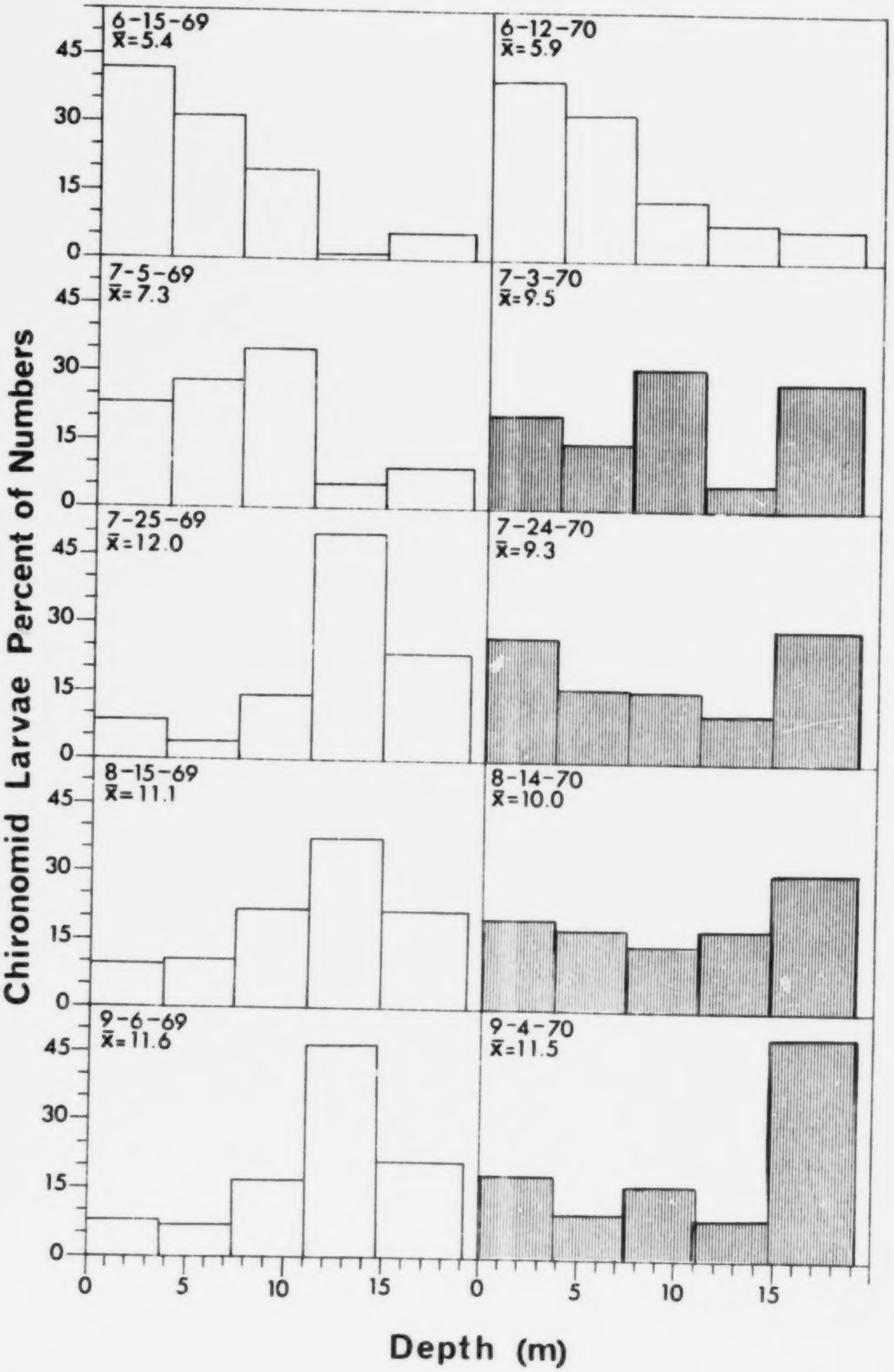
Chironomid larvae were abundant at all depths both years (Figures 88 and 89). Both years they were numerically most abundant in shallow water during June, but more abundant in deep water by September. Biomass distribution follows a similar trend, but the shallow water shift during June is not as pronounced. This indicates that the deep water larvae are much larger individuals, either because they are in later instars and/or different species.

Total chironomid larvae collected decreased from 8,817 during 1969 to 4,041 during 1970, and biomass decreased from 2.16182 gm during 1969 to 0.59028 gm during 1970. These are 54% and 73% decreases respectively. Average size also decreased from 4,078/gm during 1969 to 6,846/gm during 1970. Contrary to changes in oligochaete population trends, Chironomid larvae were less abundant during the entire summer 1970, compared to 1969 (Figure 90). The mid-June samples were taken before aeration began. These first samples indicate that the larvae were numerically less than 50% as abundant during 1970, but almost as abundant in regards to biomass.

Chironomid pupae show the same numerical shift from shallow to deep water during the summer 1970 as do the

Figure 88. Section Four Chironomid larvae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

322



6-15-69
x̄=5.4
6-12-70
x̄=5.9
7-5-69
x̄=7.3
7-3-70
x̄=9.5
7-25-69
x̄=12.0
7-24-70
x̄=9.3
8-15-69
x̄=11.1
8-14-70
x̄=10.0
9-6-69
x̄=11.6
9-4-70
x̄=11.5
45
30
15
0
Chironomid Larvae Percent of Numbers
0
5
10
15
Depth (m)

Figure 89. Section Four Chironomid larvae depth distribution as percent of wet weight during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

324

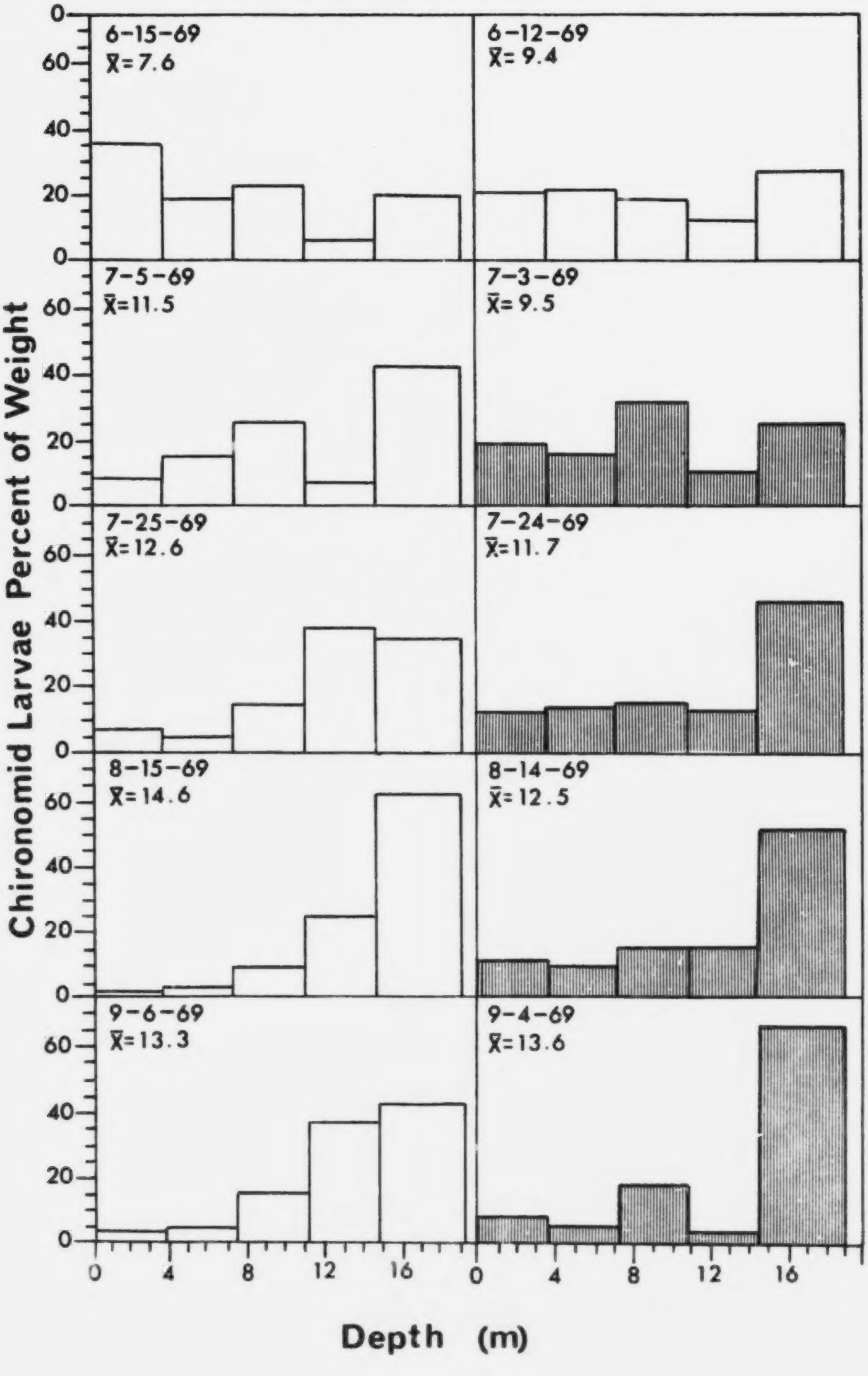
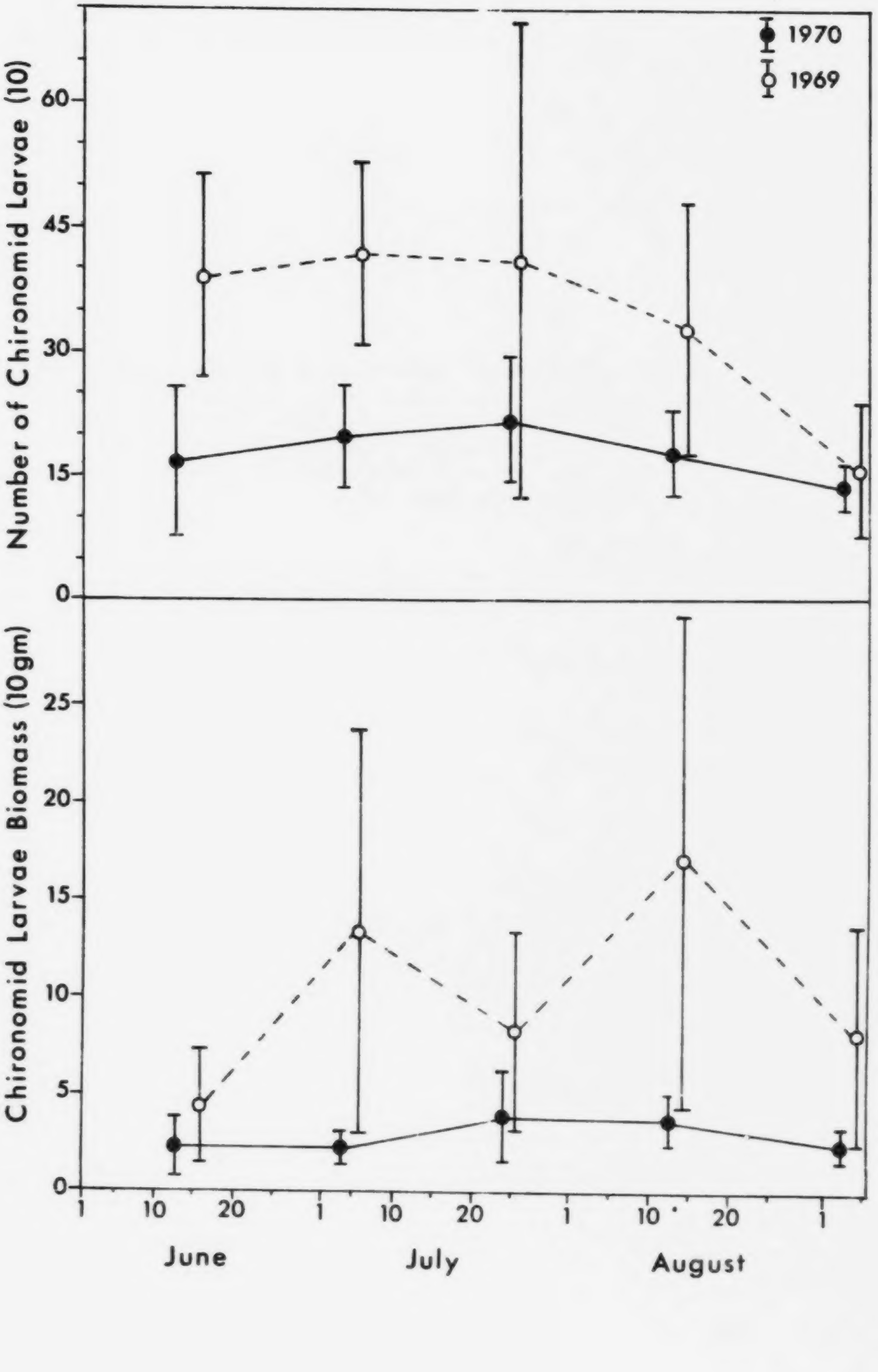

6-15-69
X̄=7.6
6-12-69
X̄=9.4
7-5-69
X̄=11.5
7-3-69
X̄=9.5
7-25-69
X̄=12.6
7-24-69
X̄=11.7
8-15-69
X̄=14.6
8-14-69
X̄=12.5
9-6-69
X̄=13.3
9-4-69
X̄=13.6
Chironomid Larvae Percent of Weight
0
20
40
60
0
4
8
12
16
Depth (m)

Figure 90. Total estimated Chironomid larvae number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.

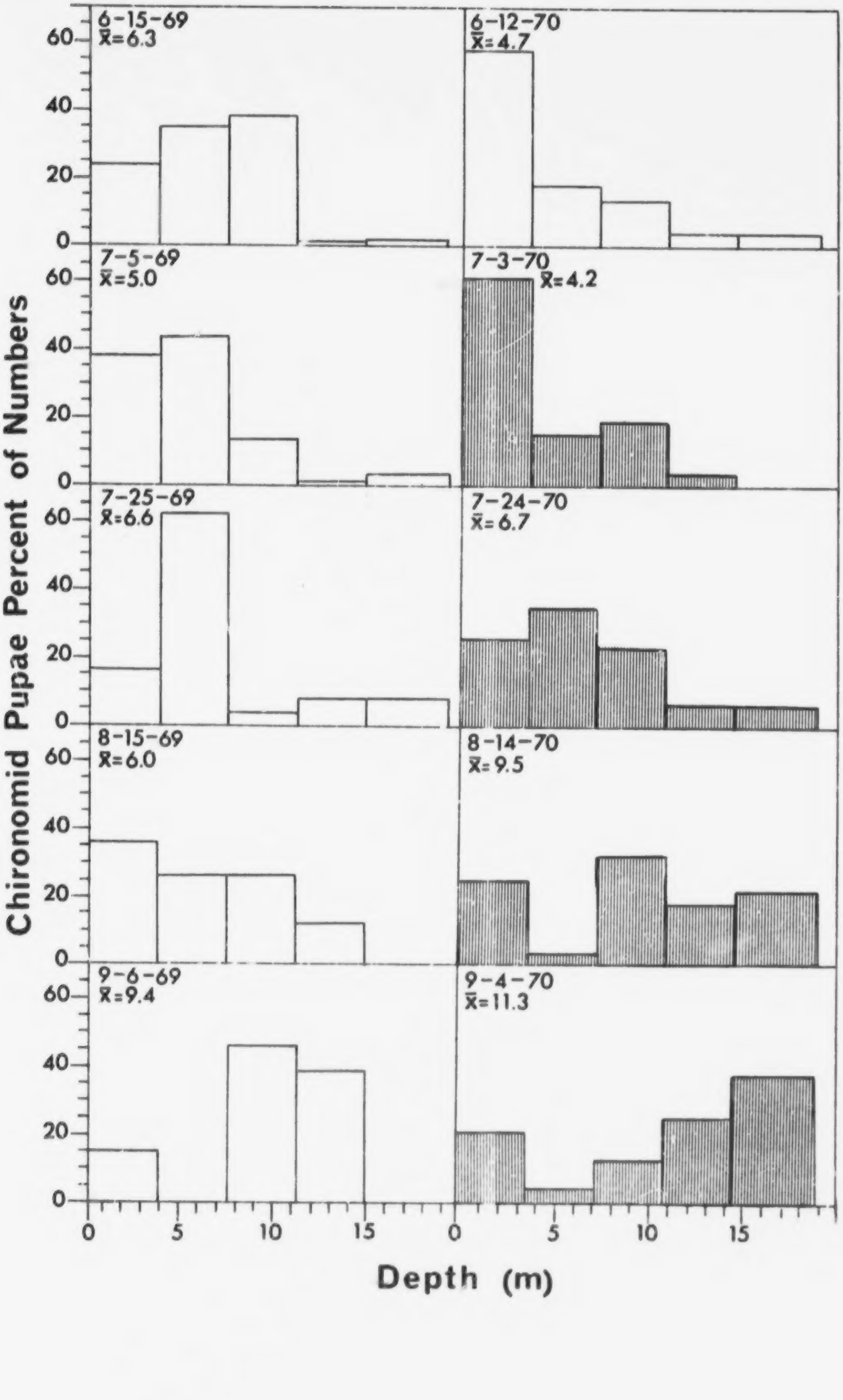

Number of Chironomid Larvae (10)
Chironomid Larvae Biomass (10gm)
1970
1969
60
45
30
15
0
25
20
15
10
5
0
1
10
20
1
10
20
1
10
20
1
June
July
August

larvae (Figure 91). Over 55% by numbers were collected from the shallowest interval during June 1970 and 5% from the deepest. By September, only 20% were collected from the shallow interval and over 30% from the deepest. The June 1970 pupal biomass distribution is more uniform than their numeric distribution, but by September 1970 over 80% were collected from the deepest intervals (Figure 92). Pupal distributions during 1969 are not as definite as during 1970, but indicate greatest concentrations between 4 and 11 meters during most of the summer. Few pupae were collected below 15 meters at any time and none were collected below 15 meters during July and August 1969.

Total pupal biomass collected increased to 0.63301 gm during 1970 from 0.05490 gm during 1969. However, total numbers decreased from 336 during 1969 to 163 during 1970 (Table 8). This represents a considerable increase in average size of the pupae during 1970. They increased from 6,120/gm during 1969 to 257/gm during 1970. Total estimated pupal population trends are less spectacular (Figure 93). Both numerically and biomass-wise pupae tended to be more abundant during early summer 1969 than during 1970, and then tended towards equal or slightly higher values by late summer 1970.

Total adult emergence reflects the decreases in larval and pupal standing crops. Only 72 adults emerged during 1970 compared to 812 for 1969 (Table 9). Although total emergence was less during 1970, they occurred in more samples

Figure 91. Section Four Chironomid pupae depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.



6-15-69
x̄=6.3
6-12-70
x̄=4.7
7-5-69
x̄=5.0
7-3-70
x̄=4.2
7-25-69
x̄=6.6
7-24-70
x̄=6.7
8-15-69
x̄=6.0
8-14-70
x̄=9.5
9-6-69
x̄=9.4
9-4-70
x̄=11.3
0
20
40
60
0
5
10
15
Chironomid Pupae Percent of Numbers
Depth (m)

Figure 92. Section Four Chironomid pupae depth distribution as percent of wet weight during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

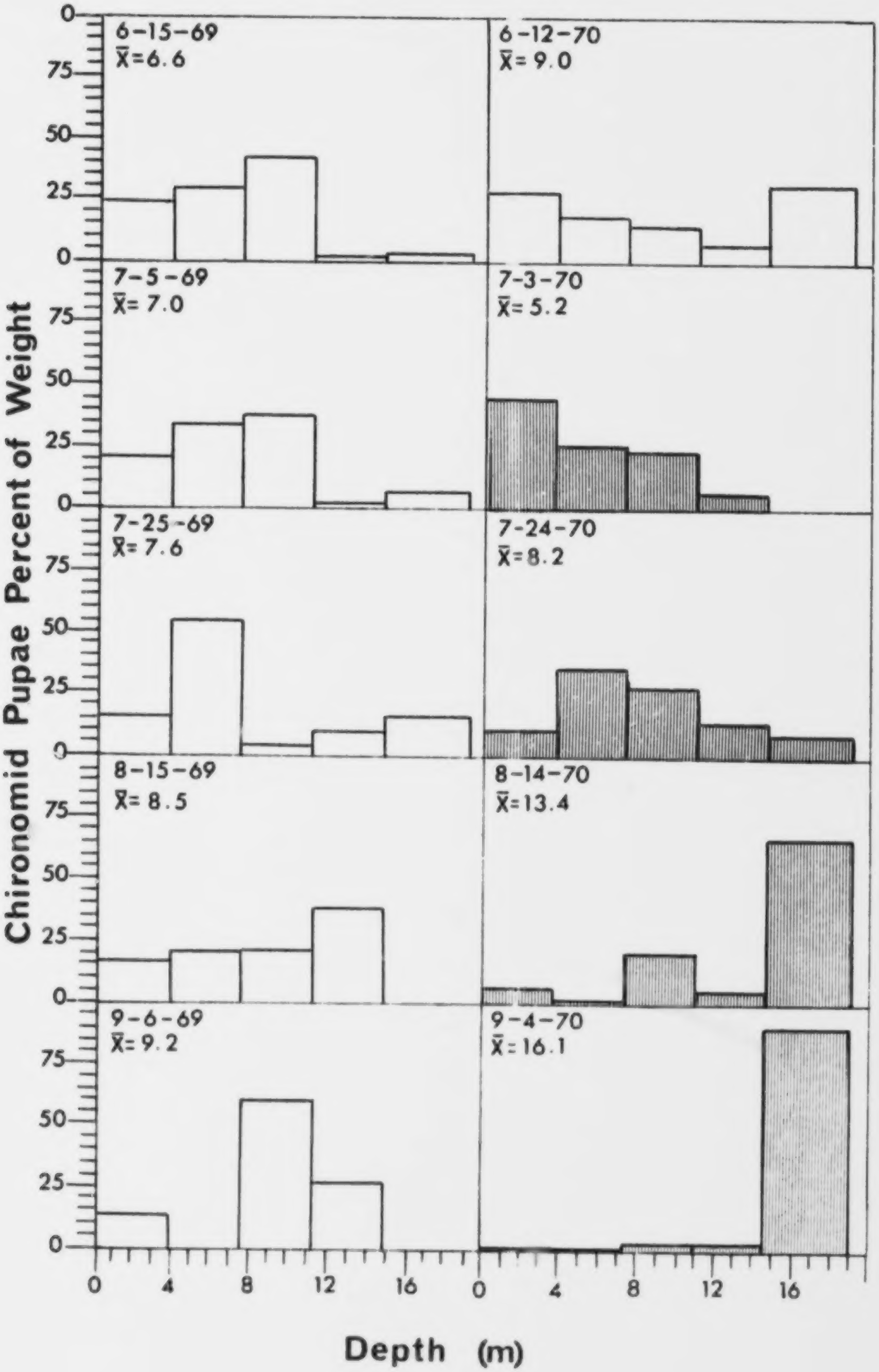
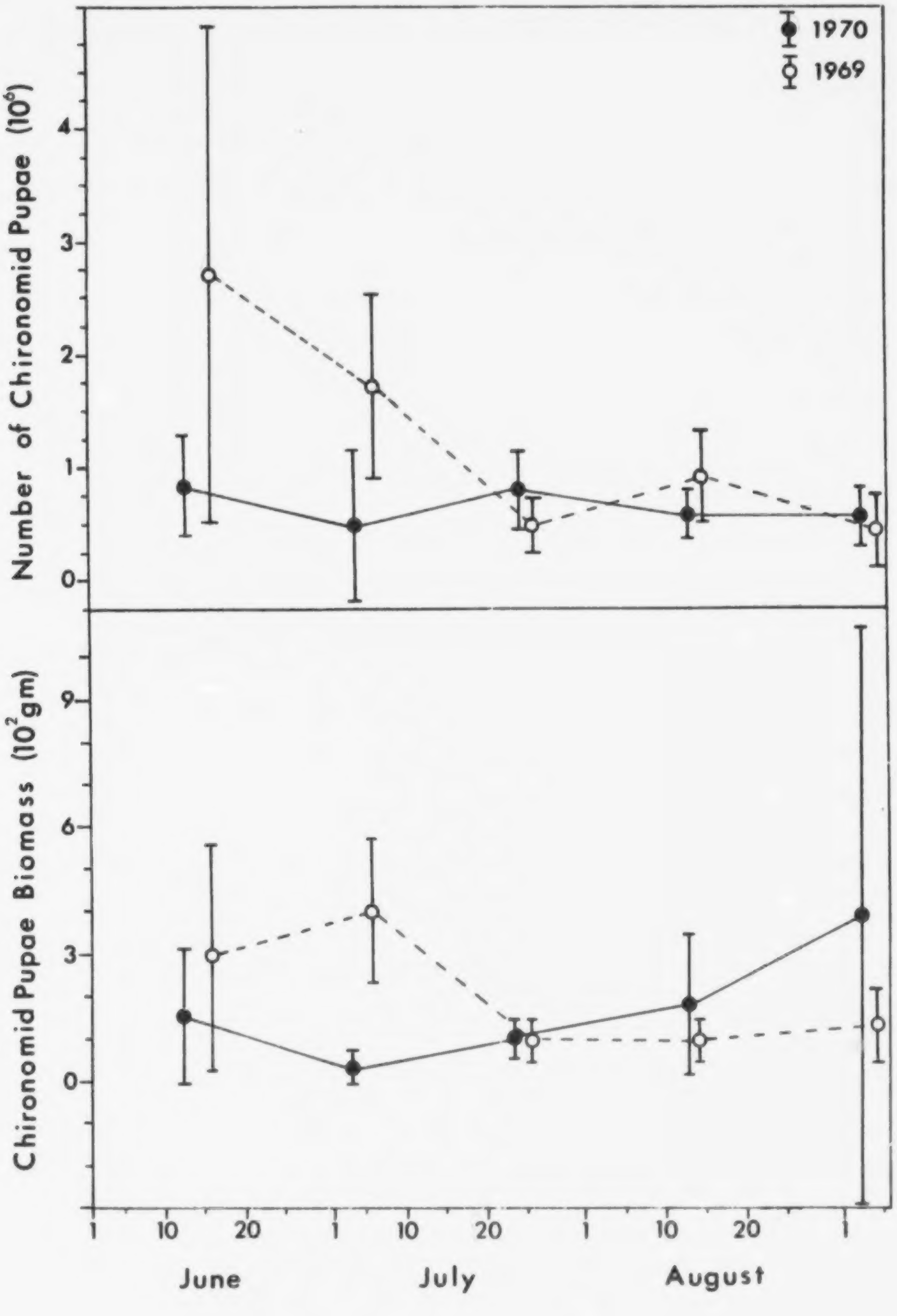

Chironomid Pupae Percent of Weight
0
75
50
25
0
6-15-69
X̄=6.6
6-12-70
X̄=9.0
7-5-69
X̄=7.0
7-3-70
X̄=5.2
7-25-69
X̄=7.6
7-24-70
X̄=8.2
8-15-69
X̄=8.5
8-14-70
X̄=13.4
9-6-69
X̄=9.2
9-4-70
X̄=16.1
0
4
8
12
16
0
4
8
12
16
Depth (m)

Figure 93. Total estimated Chironomid pupae number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.



● 1970
○ 1969
Number of Chironomid Pupae (10^6)
0
1
2
3
4
Chironomid Pupae Biomass (10^2gm)
0
3
6
9
1
10
20
1
10
20
1
10
20
1
June
July
August

during 1970 than during 1969, 408 compared to 381. This change is reflected in a more uniform depth emergence following destratification (Figure 94). During 1969, almost all emergence was limited to less than 4 meters. No midges emerged below 12 meters after mid-July 1969. During mid-June 1970, emergence was again largely limited to less than 4 meters, but as aeration continued emergence increased at the greater depths. Between 20% and 40% of the total emergence occurred below 12 meters during August and September 1970, whereas none occurred in this interval during the same period of 1969.

Total seasonal emergence was generally greater during 1969 (Figure 95). Two large peaks occurred during 1969, one during mid-July and another during mid-August. These coincide closely with periods of intense heating (Figure 73). Emergence during 1970 has several peaks, but these coincidences with periods of heating are obscure after mid-July.

Of the more abundant Chironomid adults, only _Ablabesmyia mallochi_ and _Clinotanypus thoracicus_ showed much increase in emergence during 1970 (Table 9; Figure 96). The other species either remained about the same or declined. These two species belong to the predaceous sub-family Pelopiinae. Of the more abundant adults, only _C. thoracicus_ showed much change in its emergence depth (Figures 97 and 98). Over 50% of this species emerged below 16 meters during 1970 during its peak emergence period. Its emergence during 1969 was

Figure 94. Total midge emergence from Section Four by depths during the summers 1969 and 1970. Aeration occurred between June 16 and September 7, 1970. Totals include Chironomid midges from emergence traps only.

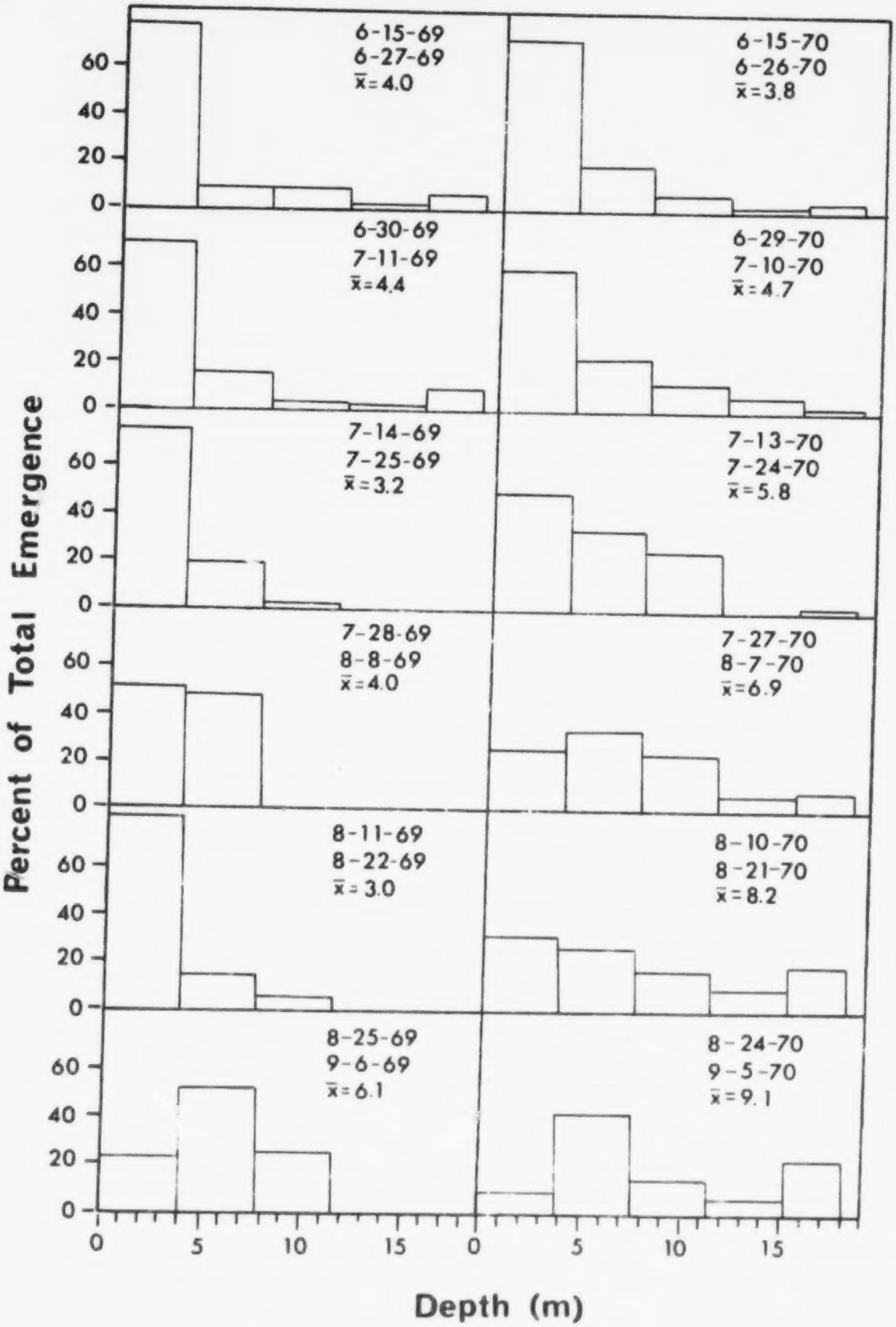

6-15-69
6-27-69
x̄=4.0
6-15-70
6-26-70
x̄=3.8
6-30-69
7-11-69
x̄=4.4
6-29-70
7-10-70
x̄=4.7
7-14-69
7-25-69
x̄=3.2
7-13-70
7-24-70
x̄=5.8
7-28-69
8-8-69
x̄=4.0
7-27-70
8-7-70
x̄=6.9
8-11-69
8-22-69
x̄=3.0
8-10-70
8-21-70
x̄=8.2
8-25-69
9-6-69
x̄=6.1
8-24-70
9-5-70
x̄=9.1
Percent of Total Emergence
0
20
40
60
0
5
10
15
Depth (m)

Figure 95. Total estimated weekly midge emergence from Section Four during the summers 1969 and 1970. Totals include Chironomid midges from emergence traps only. Aeration occurred continuously between June 16 and September 7, 1970.

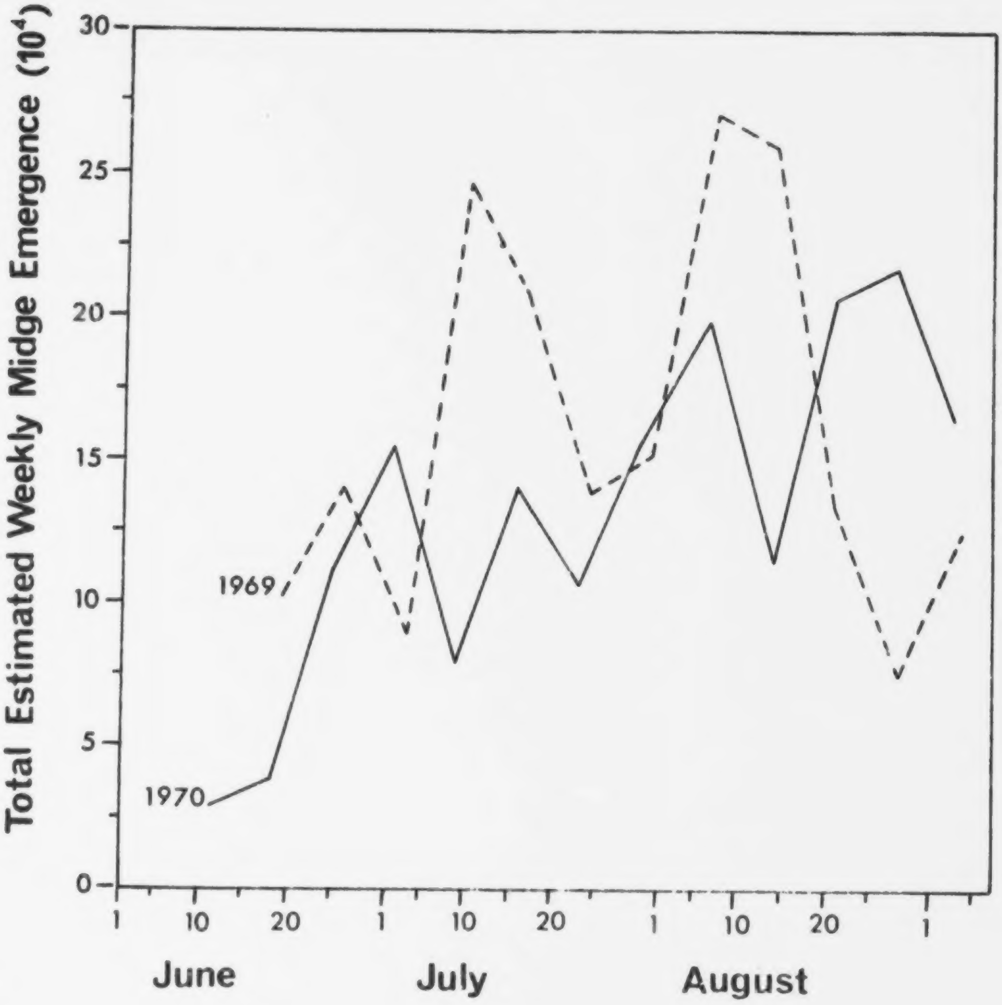
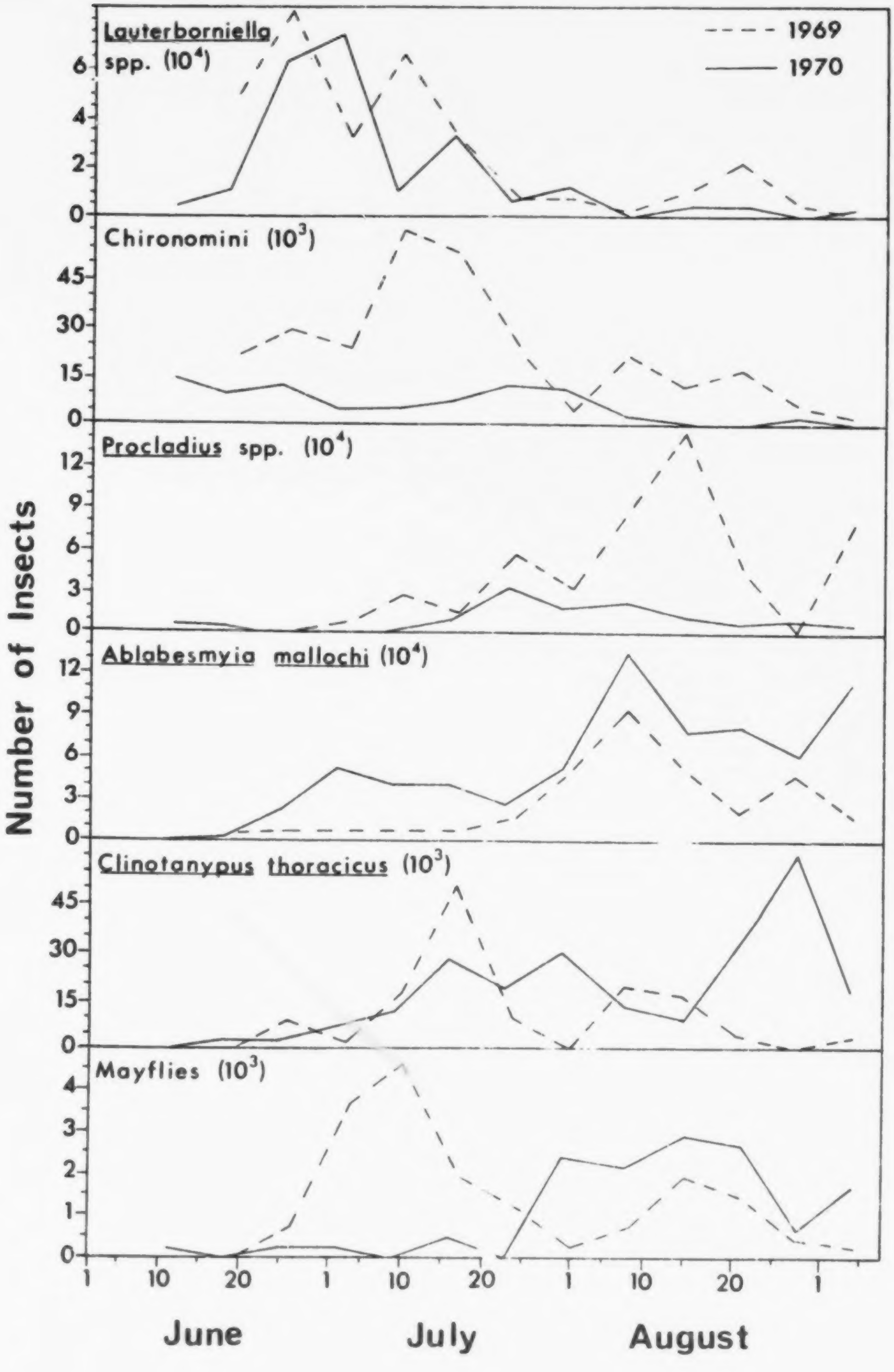

Total Estimated Weekly Midge Emergence (10^4)
30
25
20
15
10
5
0
1969
1970
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 96. Total estimated midge emergences from Section Four. Samples from emergence traps only. Aeration occurred between June 16 and September 7, 1970.

340



Lauterborniella spp. (10^4)
Chironomini (10^3)
Procladius spp. (10^4)
Ablabesmyia mallochi (10^4)
Clinotanypus thoracicus (10^3)
Mayflies (10^3)
1969
1970
Number of Insects
0
2
4
6
15
30
45
3
6
9
12
1
1
10
20
June
July
August

Figure 97. Depth emergence of selected Section Four midges during the summers 1969 and 1970. White areas represent no observed emergence. A= *Procladius*, B= *Ablabesmyia mallochi*, C= *Clinotanypus thoracicus*. Aeration occurred between June 16 and September 7, 1970.

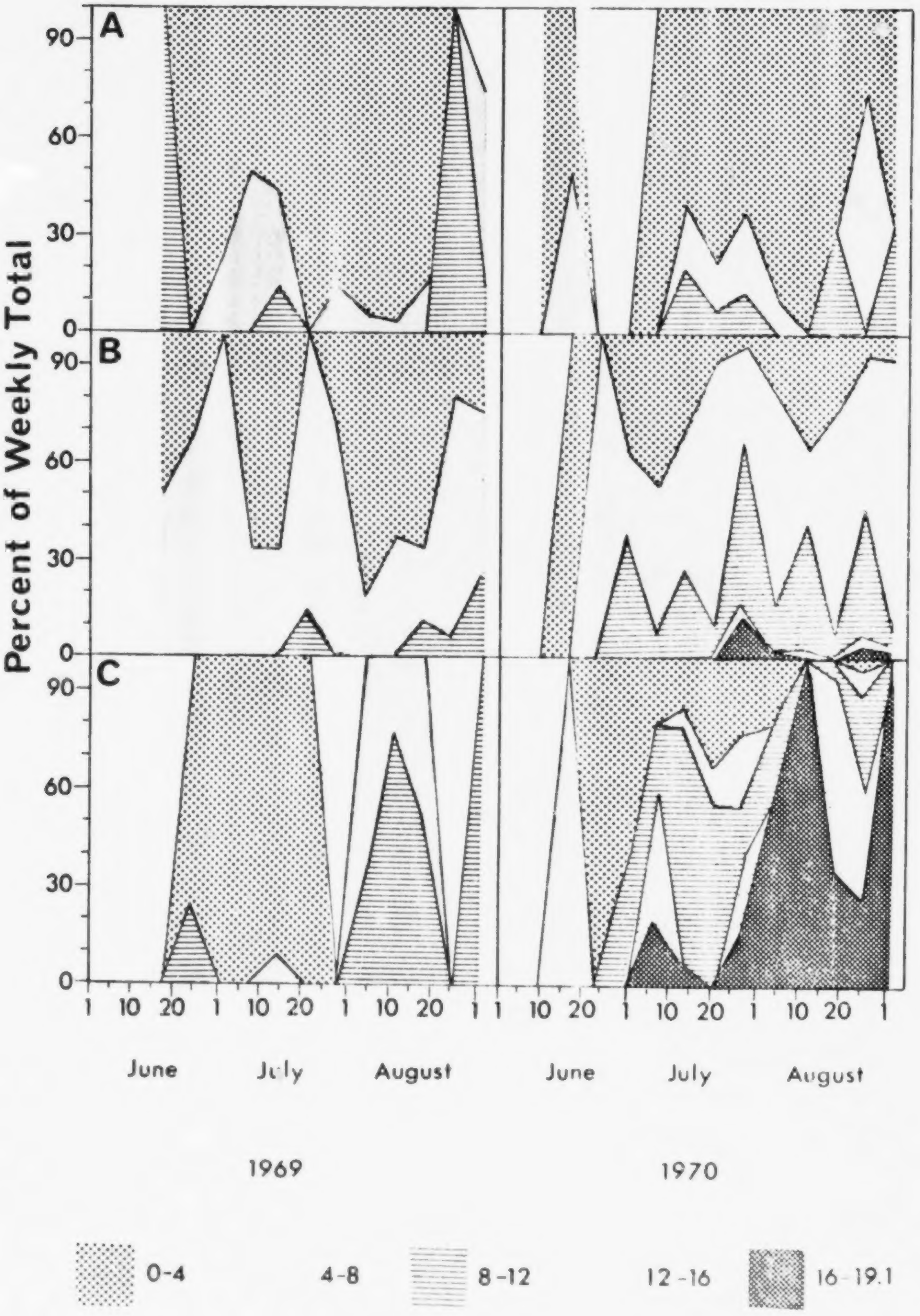
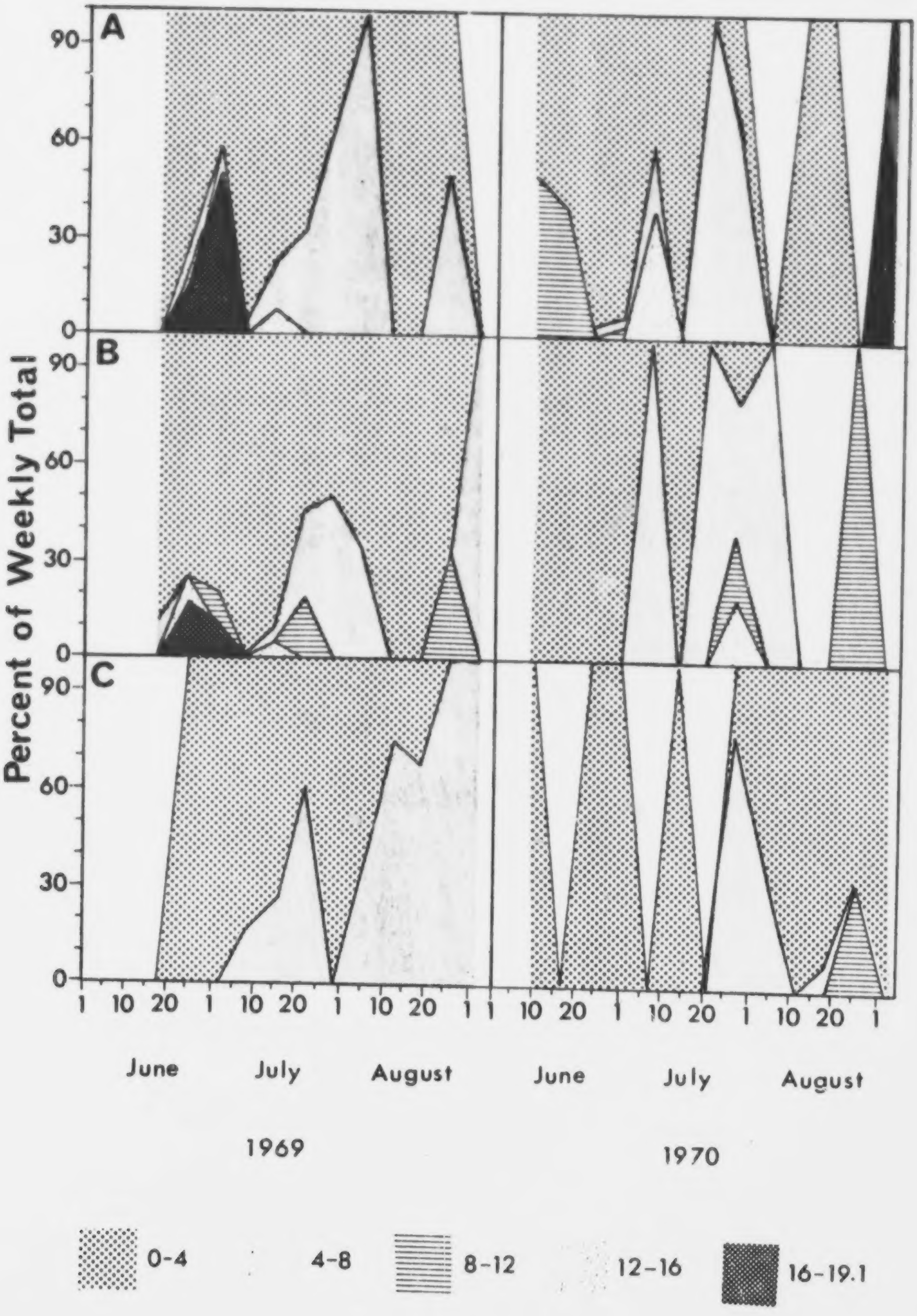

A
B
C
Percent of Weekly Total
90
60
30
0
1
10
20
June
July
August
1969
1970
0-4
4-8
8-12
12-16
16-19.1

Figure 98. Depth emergence of Section Four midges and mayflies during the summers 1969 and 1970. White areas represent no observed emergence. A= *Lauterborniella* spp., B= *Chironomini*, C= Mayflies (Ephemeroptera). Aeration occurred between June 16 and September 7, 1970.


A
B
C
Percent of Weekly Total
0
30
60
90
1
10
20
June
July
August
1969
1970
0-4
4-8
8-12
12-16
16-19.1

limited to less than 12 meters during the entire summer. A. mallochi also increased its emergence depth substantially during August 1970, but not as much as C. thoracicus. Changes in the other species were erratic.

N. Wilson Britt identified four species of mayflies from Section Four: Caenis spp., Callibaetis spp. (probably C. brevisostatus), Neocloeon alamance and Stenonema spp. Caenis was the most abundant. Mayfly nymph biomass collected by the dredges decreased by 55% during 1970 compared to 1969, but total number collected were almost identical both years (Table 8). Total estimated nymph biomass was always less during 1970 (Figure 100). Total numbers were less during early summer 1970 but exceeded the 1969 values during August 1970. Nymph depth distribution was very similar both years (Figure 99). Nymphs were seldom collected below 11 meters depth. They were never collected below 14.5 meters, and were only abundant between 11 and 14.5 meters during September 1970. The emergence depth distribution largely reflects the nymph distribution (Figure 98). Adults never emerged below 8 meters during 1969. Their peak emergence occurred during early July 1969, at which time most emerged from between 0 and 4 meters depth. By the end of the summer 1969, all were emerging from between 4 and 8 meters depth. Their 1970 emergence pattern differed greatly from the 1969 pattern in both time and depth of emergence. The 1970 peak emergence occurred during August, with almost no emergence before the

Figure 99. Section Four Mayfly (Ephemeroptera) depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

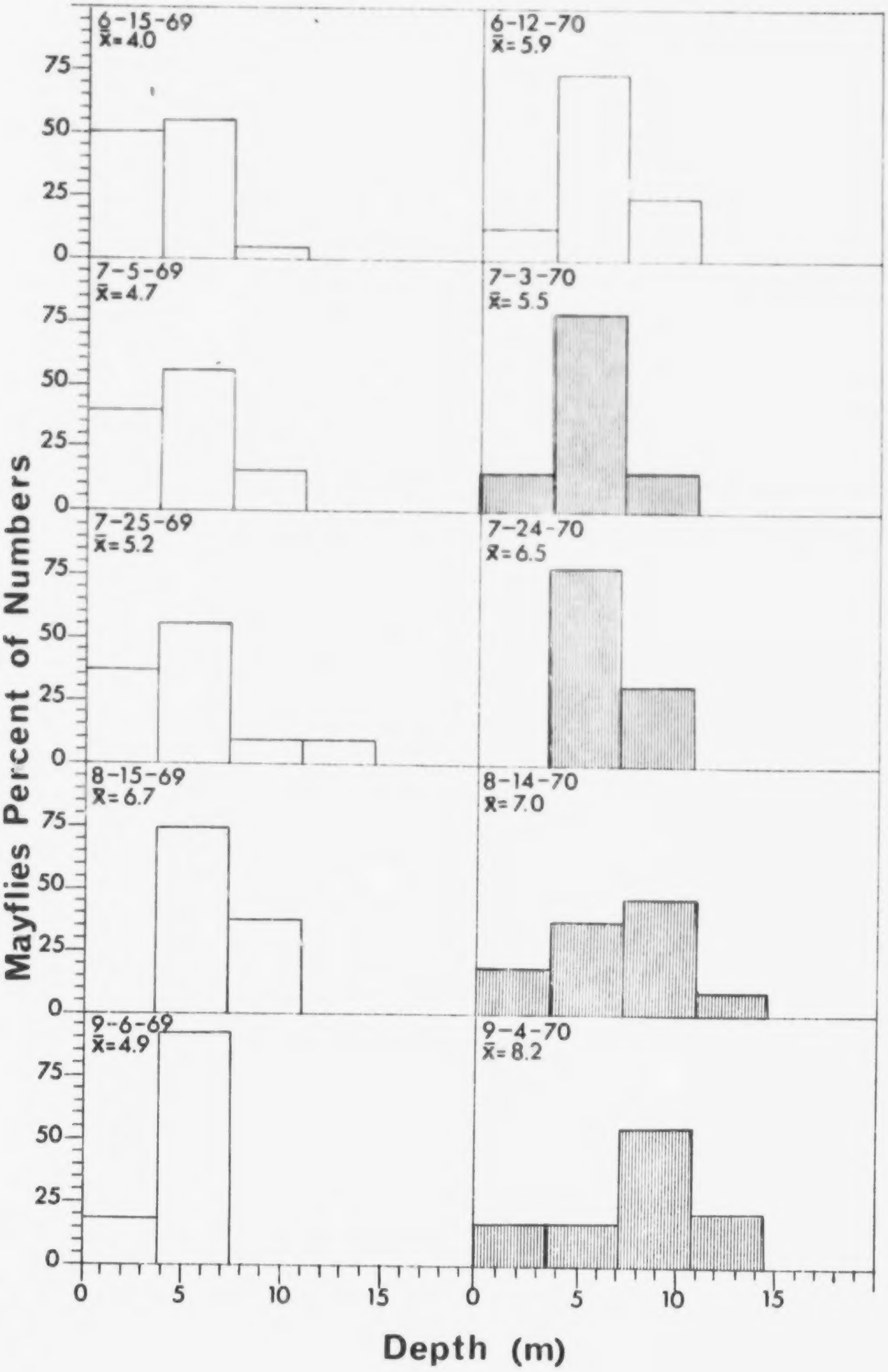
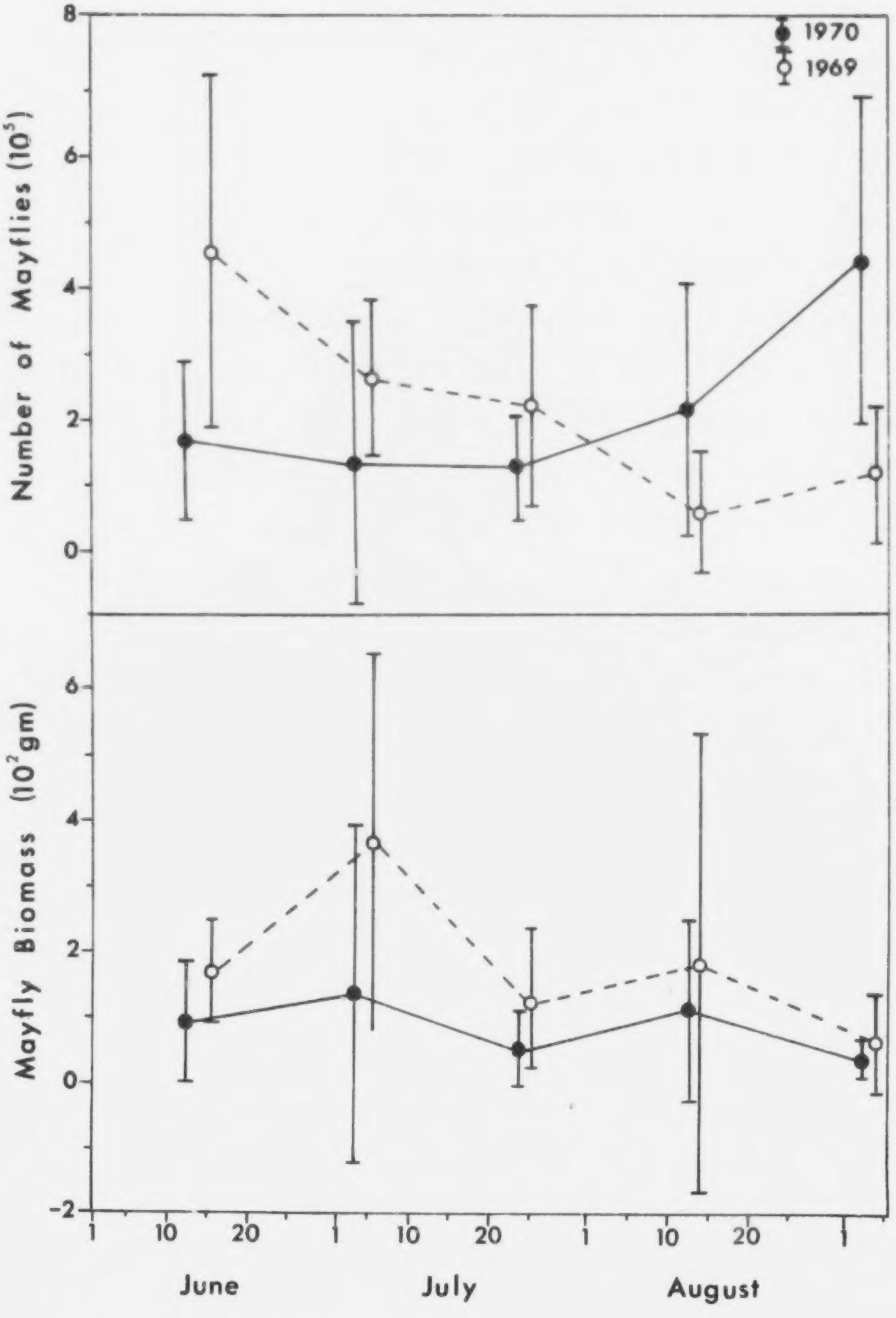

6-15-69
x̄=4.0
6-12-70
x̄=5.9
7-5-69
x̄=4.7
7-3-70
x̄=5.5
7-25-69
x̄=5.2
7-24-70
x̄=6.5
8-15-69
x̄=6.7
8-14-70
x̄=7.0
9-6-69
x̄=4.9
9-4-70
x̄=8.2
0
25
50
75
0
5
10
15
Mayflies Percent of Numbers
Depth (m)

Figure 100. Total estimated Mayfly (Ephemeroptera) number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.



8
6
4
2
0
Number of Mayflies (10^5)
1970
1969
6
4
2
0
-2
Mayfly Biomass (10^2gm)
1
10
20
1
10
20
1
10
20
1
June
July
August

end of July. The early summer emergence was entirely from between 0 and 4 meters, but the August 1970 emergence occurred from between 0 and 12 meters.

Two species of Amphipods were identified by T. Wayne Porter: *Hyalella azteca* and *Gamarus*. *H. azteca* was by far the most abundant. Total amphipod biomass was about the same both years, but about 32% more individuals were collected during 1970 (Table 8; Figure 101). Their depth distributions are about the same both years (Figure 102), with almost no specimens collected below 14.5 meters.

Four Trichoptera were identified by Glenn B. Wiggins (Royal Ontario Museum): *Mystacides* spp., *Oecetis* spp., *Polycentropus* and *Oxyethira* in order of relative abundance. Trichoptera numbers, biomass and depth distribution were about the same both years (Table 8; Figures 103 and 104).

Leonora K. Gloyd identified six Odonates from Section Four: Dragonflies: *Gomphus* spp. (probably *G. spicatus*), *G. quadricolor* (or possibly *G. lividus*); Damselflies: *Ischnora verticallis*, *Enallagma hageni*, *Argia* spp. (probably *A. fumipennis violacea*) and *E. ebrium* (or possibly *E. hageni*). Odonata numbers and biomass were about the same both years (Table 8).

Heleidae (=Ceratopogonidae) larval biomass and numbers decreased by about 50% during 1970 compared to 1969 (Table 8; Figure 105). Their depth distributions were erratic, with no obvious trends (Figure 106).

Figure 101. Total estimated Amphipod number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.

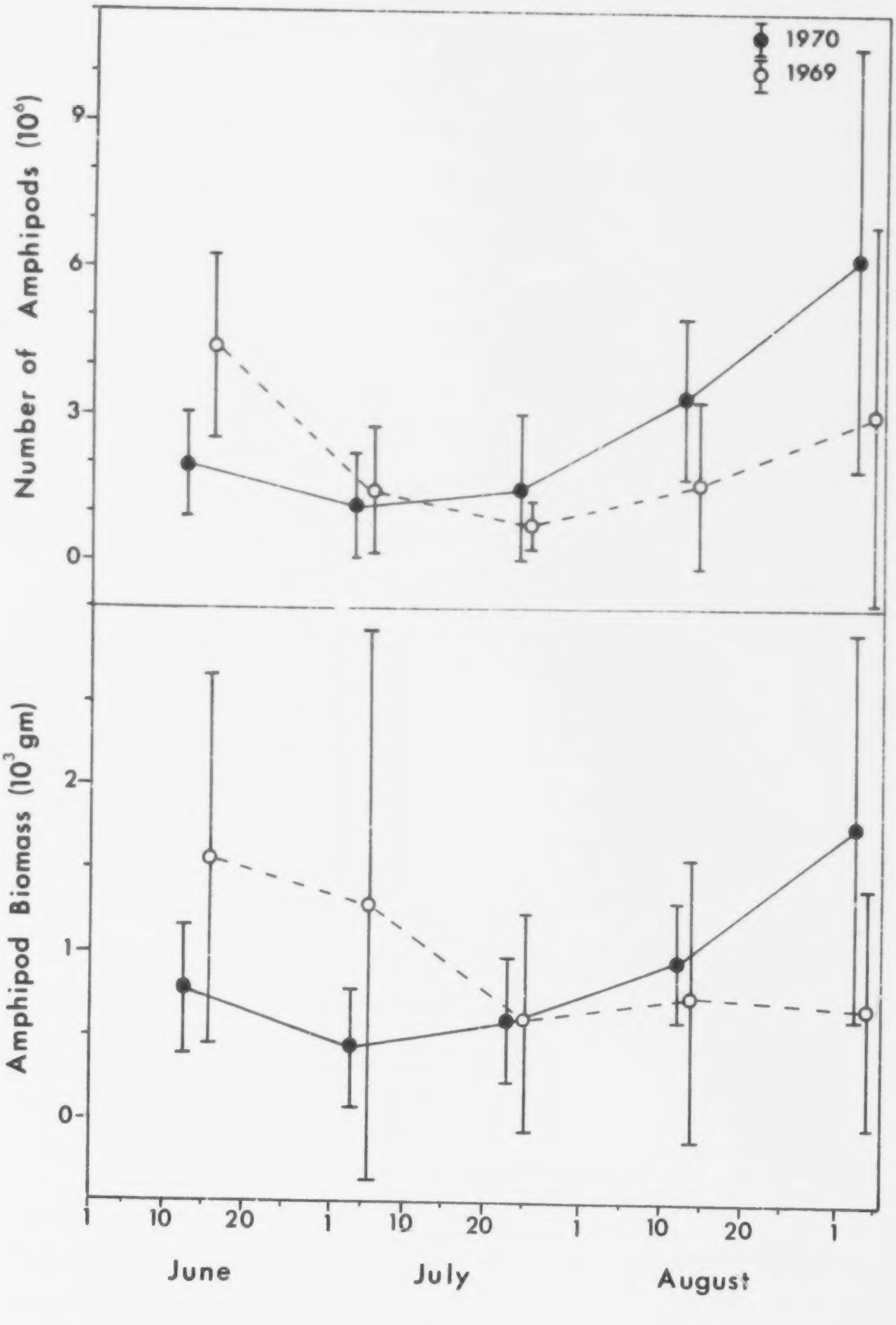

● 1970
○ 1969
Number of Amphipods (10^6)
9
6
3
0
Amphipod Biomass (10^3gm)
2
1
0
1
10
20
1
10
20
1
10
20
1
June
July
August

Figure 102. Section Four Amphipod depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

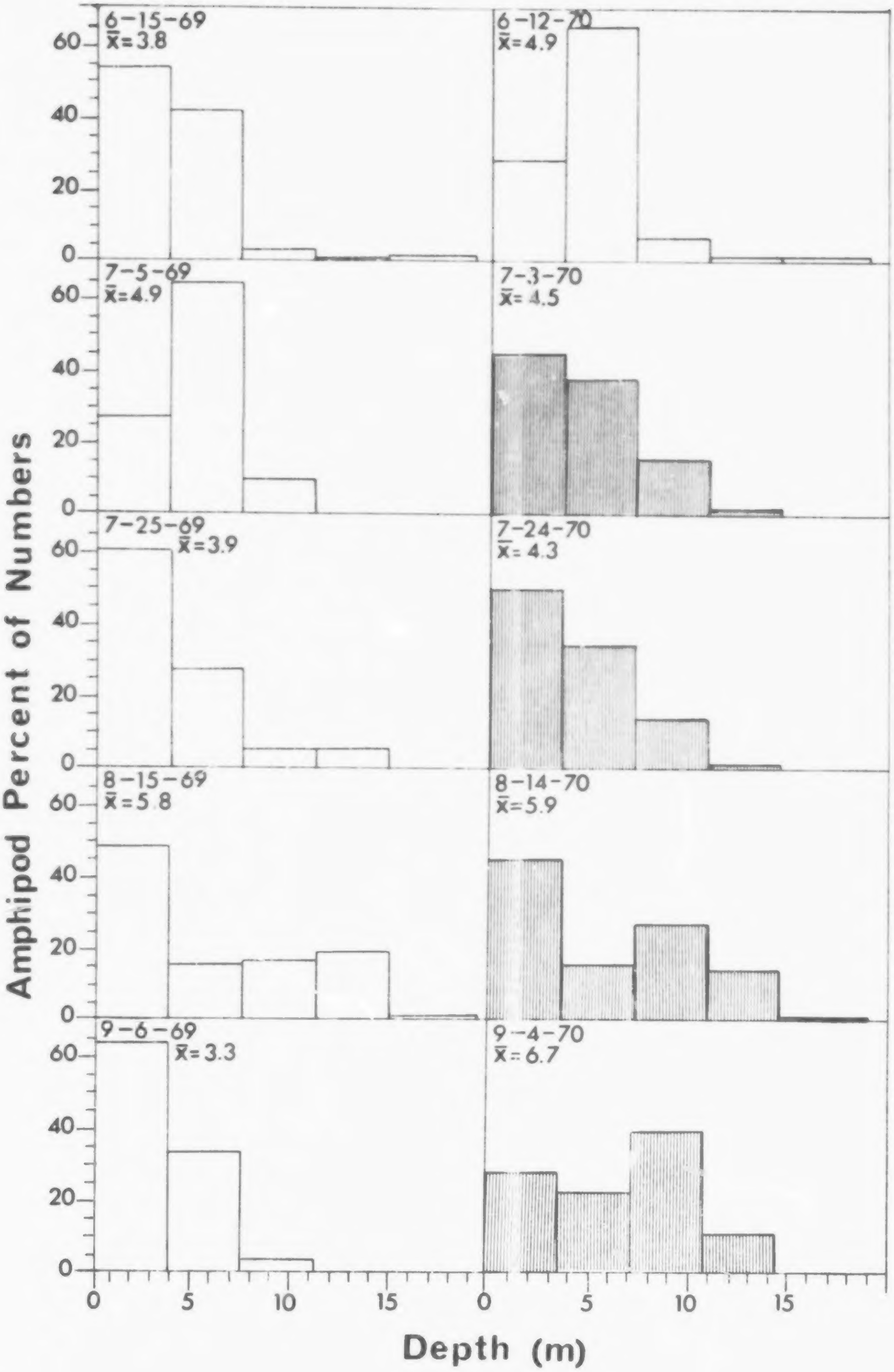

6-15-69
x̄=3.8
6-12-70
x̄=4.9
7-5-69
x̄=4.9
7-3-70
x̄=4.5
7-25-69
x̄=3.9
7-24-70
x̄=4.3
8-15-69
x̄=5.8
8-14-70
x̄=5.9
9-6-69
x̄=3.3
9-4-70
x̄=6.7
0
20
40
60
Amphipod Percent of Numbers
0
5
10
15
Depth (m)

Figure 103. Section Four Trichoptera depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

356

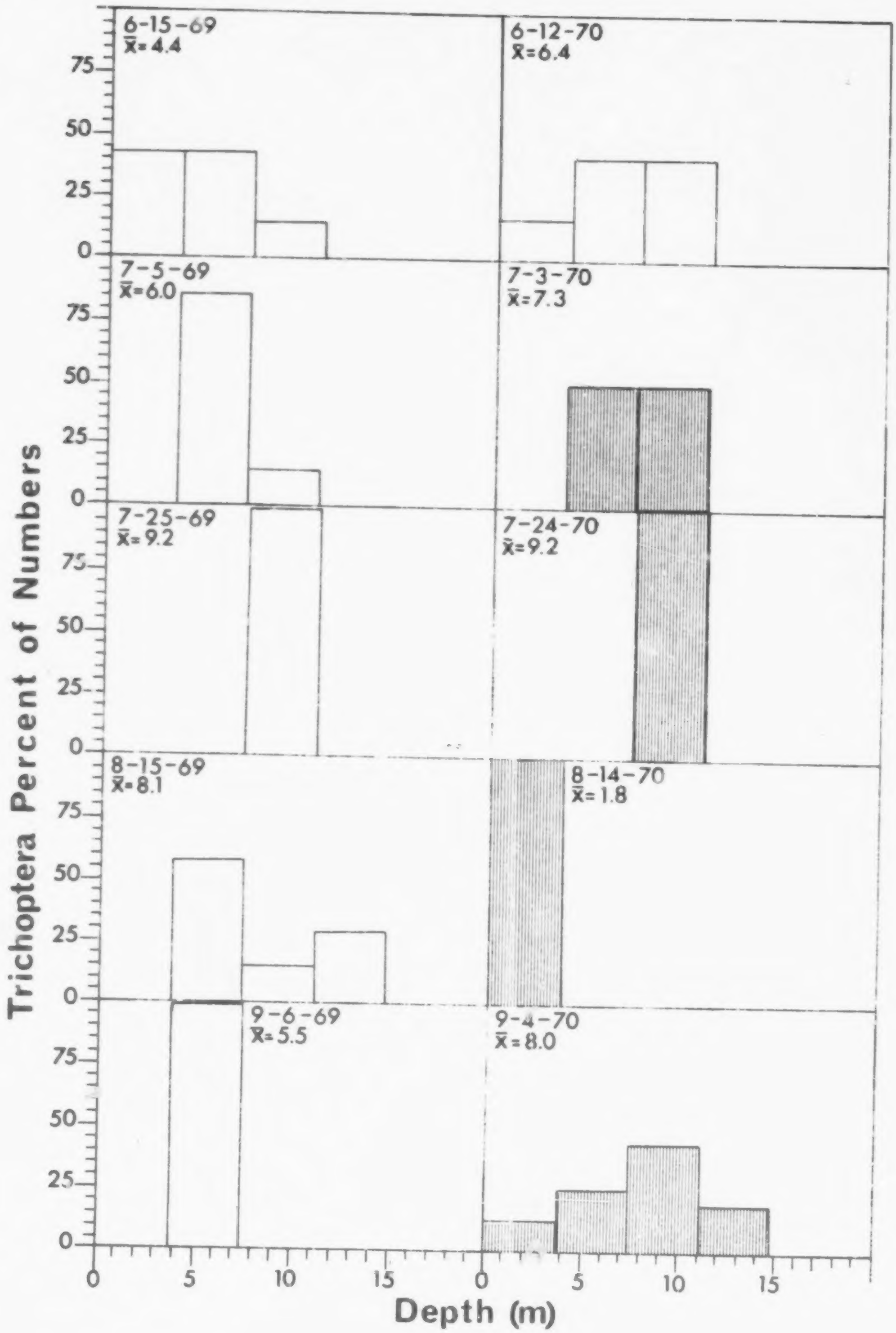

6-15-69
x̄=4.4
6-12-70
x̄=6.4
7-5-69
x̄=6.0
7-3-70
x̄=7.3
7-25-69
x̄=9.2
7-24-70
x̄=9.2
8-15-69
x̄=8.1
8-14-70
x̄=1.8
9-6-69
x̄=5.5
9-4-70
x̄=8.0
0
25
50
75
Trichoptera Percent of Numbers
0
5
10
15
Depth (m)

Figure 104. Total estimated Trichoptera number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.

358

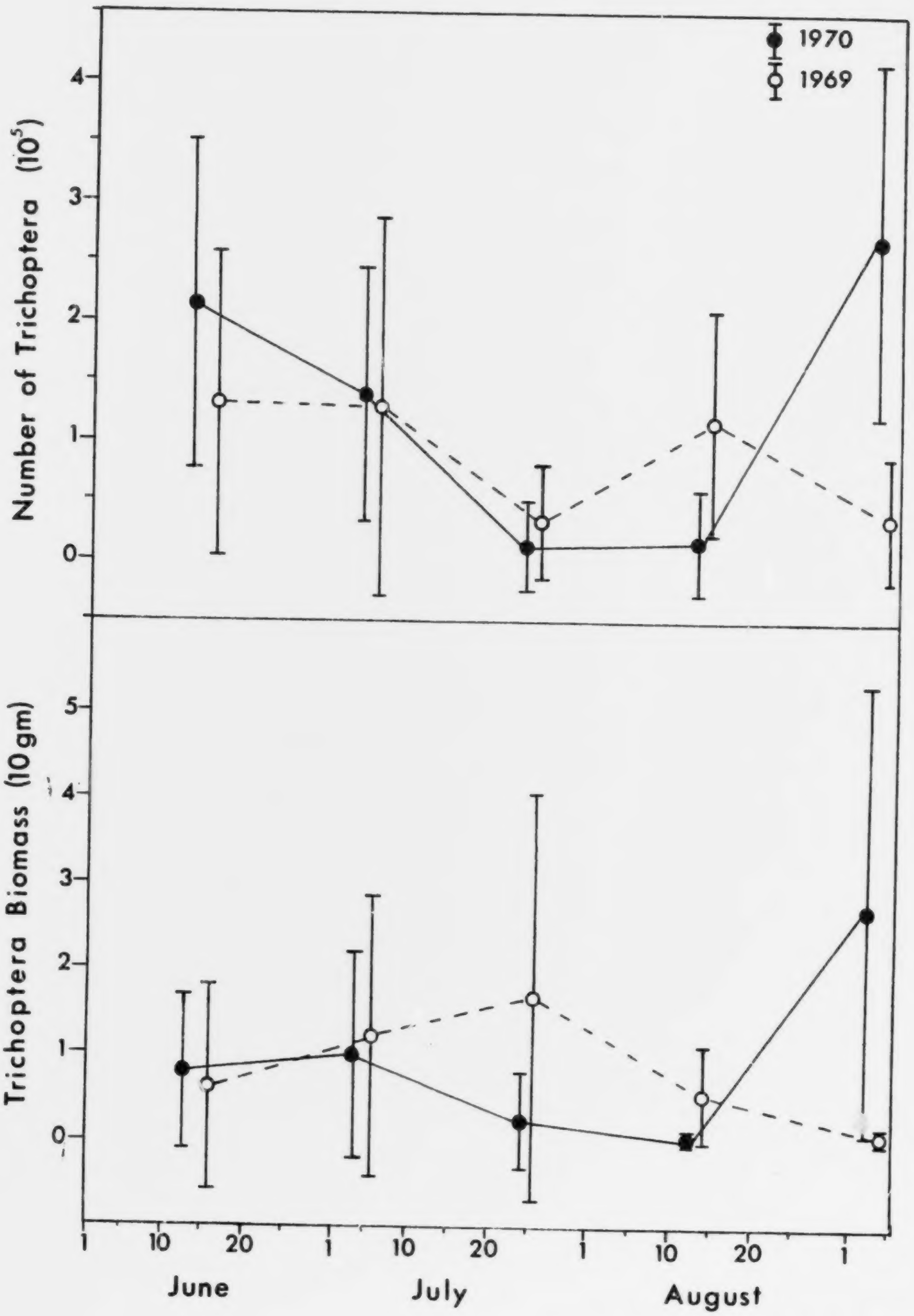
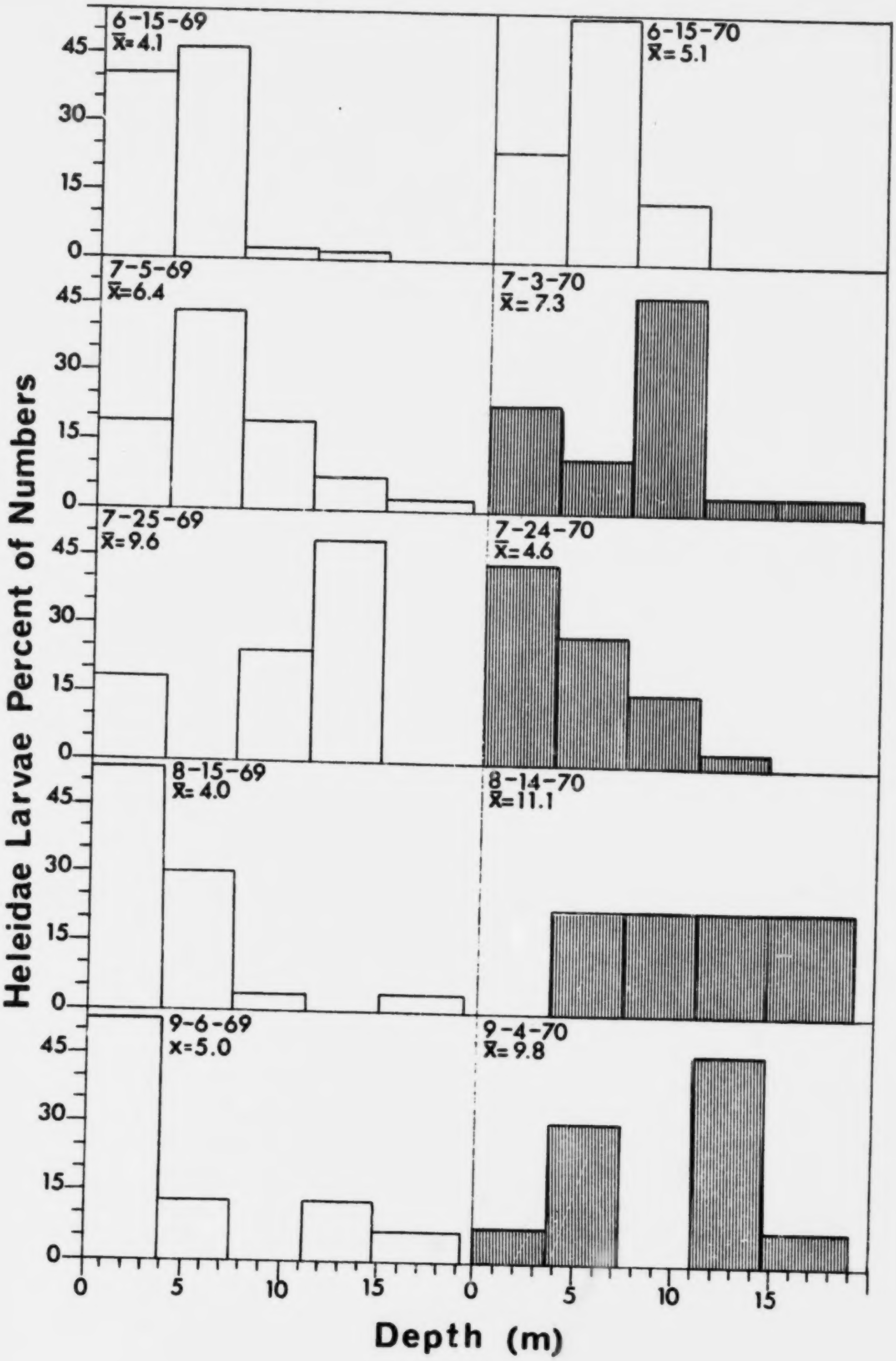

1970
1969
Number of Trichoptera (10^5)
4
3
2
1
0
Trichoptera Biomass (10gm)
5
4
3
2
1
0
1
10
20
1
10
20
1
10
20
1
June
July
August

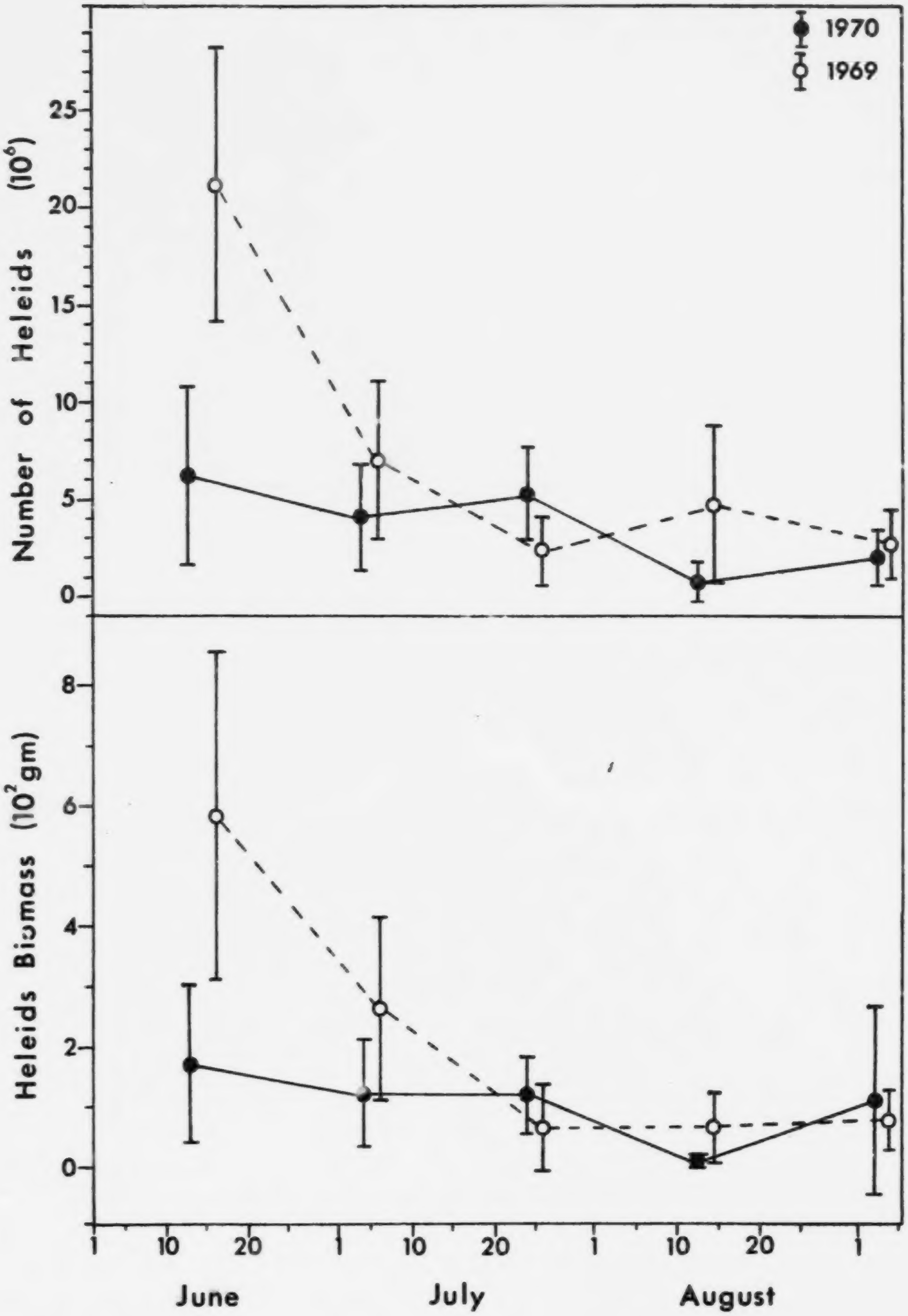
Figure 105. Section Four Heleidae (=Ceratopogonidae) depth distribution as percent of number during each sampling period during the summers 1969 and 1970. Shaded histograms represent aerated periods.

360



Heleidae Larvae Percent of Numbers
6-15-69
x̄= 4.1
6-15-70
x̄= 5.1
7-5-69
x̄=6.4
7-3-70
x̄= 7.3
7-25-69
x̄=9.6
7-24-70
x̄= 4.6
8-15-69
x̄= 4.0
8-14-70
x̄=11.1
9-6-69
x=5.0
9-4-70
x̄= 9.8
45
30
15
0
0
5
10
15
0
5
10
15
Depth (m)

Figure 106. Total estimated Heleidae (=Ceratopogonidae) number and wet weight in Section Four during the summers 1969 and 1970. One standard error is shown about each estimate. Aeration occurred between June 16 and September 7, 1970. Totals from dredge samples only.

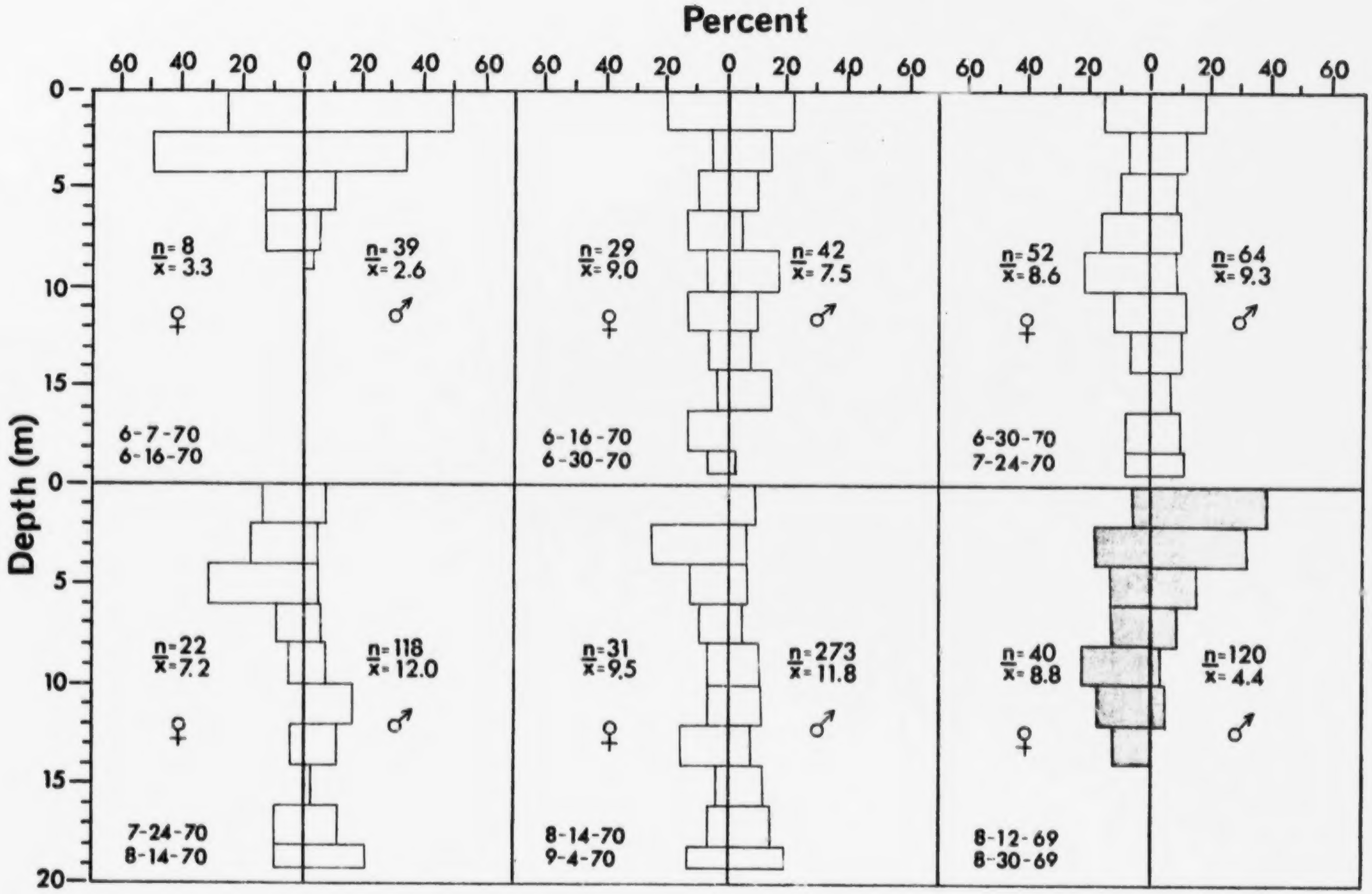

1970
1969
Number of Heleids (10⁶)
25
20
15
10
5
0
Heleids Biomass (10²gm)
8
6
4
2
0
1
10
20
1
10
20
1
10
20
1
June
July
August

Crayfish

During 1969, Section Four crayfish were only collected between August 12th and August 30th. During this period, the males were largely confined to shallow water, and the females to deeper water (Figure 107). The average depth for males was 4.4 m and 8.8 m for females. Three times as many males were captured as females. No crayfish were collected below 14 meters depth. Their maximum depth during 1969 corresponds closely with the 10°C isotherm. Although some chemical stratification was present, it did not appear to be an important barrier to crayfish depth distribution.

During early June 1970, both males and females were largely confined to shallow water. Their average depths were 2.6 m and 3.3 m respectively, with no animals below 9 meters. The lake was well-stratified thermally during this period, but chemical stratification was not evident. As during August 1969, their maximum depth distribution during early June corresponds to the 10°C isotherm. After aeration began, the crayfish very rapidly distributed to maximum depth. Aeration began June 17, 1970 and the lake was almost completely destratified within a few days. After destratification, the minimum temperature was always greater than 14°C. The females' average depth between June 16th and June 30th was 9.5 m and the males' 11.8 m. Their depth distributions varied somewhat during the remainder of the summer, but they were always distributed to maximum depth. No conspicuous

Figure 107. Section Four crayfish depth distributions during the summers 1969 and 1970. Total numbers during each sample period and their average depths are shown. The shaded area represents the 1969 distributions. Aeration occurred between June 16 and September 7, 1970.


Percent
60 40 20 0 20 40 60
Depth (m)
0 5 10 15 20
n= 8
x= 3.3
♀
n= 39
x= 2.6
♂
6-7-70
6-16-70
n= 29
x= 9.0
♀
n= 42
x= 7.5
♂
6-16-70
6-30-70
n= 52
x= 8.6
♀
n= 64
x= 9.3
♂
6-30-70
7-24-70
n= 22
x= 7.2
♀
n= 118
x= 12.0
♂
7-24-70
8-14-70
n= 31
x= 9.5
♀
n= 273
x= 11.8
♂
8-14-70
9-4-70
n= 40
x= 8.8
♀
n= 120
x= 4.4
♂
8-12-69
8-30-69

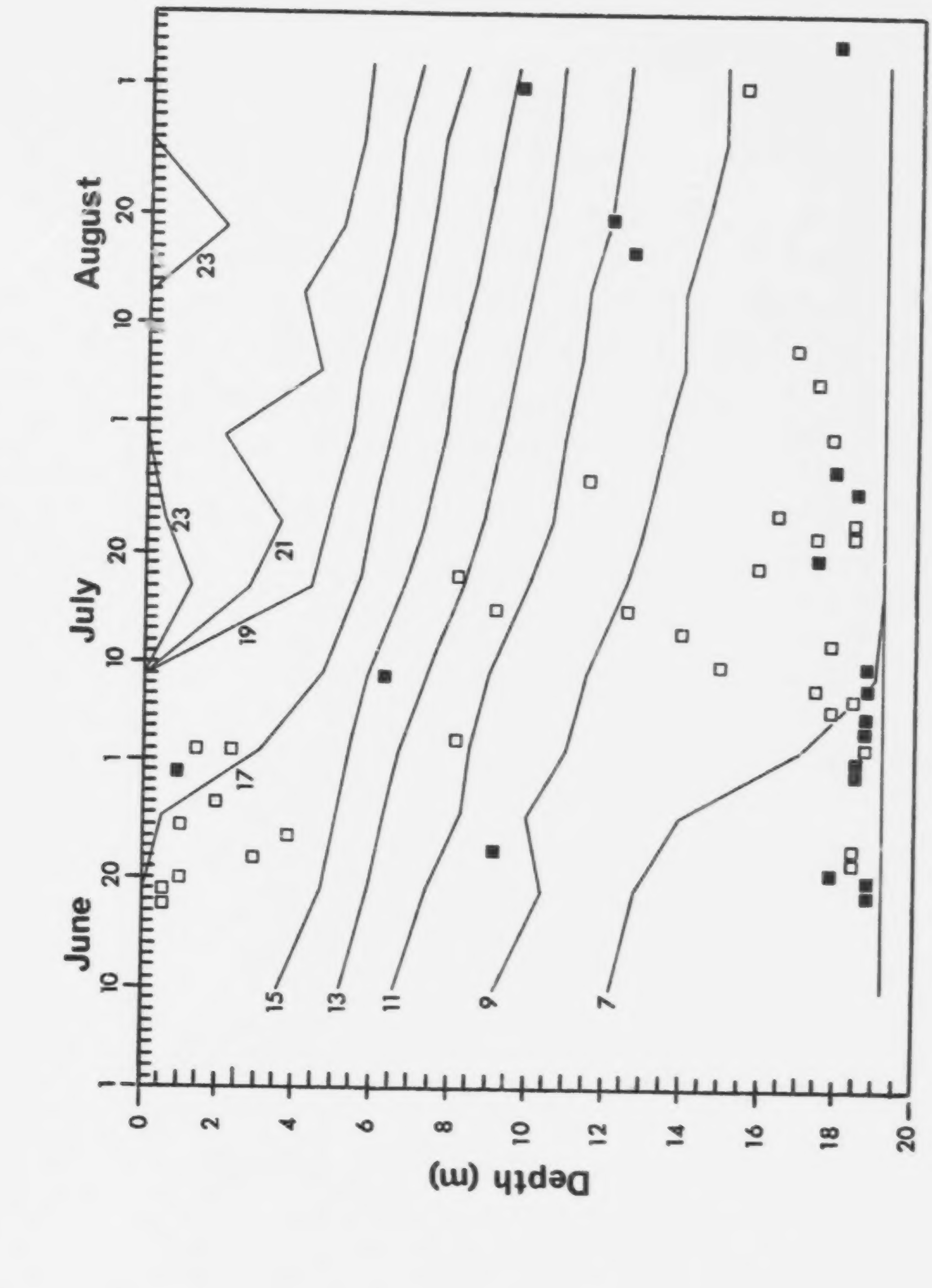
concentrations in response to environmental factors was obvious. The sex ratio was always in favor of the males. During 1969 this ratio was 1:3.0 and during 1970 it was 1:3.8.

From August 14, 1970 through September 4, 1970, the distributions were much changed from the previous year. The males were most numerous at maximum depth during 1970. Their average depth was 11.8 m during 1970 compared to 4.4 m during 1969. The females were also distributed to maximum depth (19.6 m) during 1970, compared to 14.0 m during 1969. Their average depth was only slightly greater during 1970; 9.5 m compared to 8.8 m.

Rainbow Trout

Rainbow trout ranged between the surface and bottom during June 1969 (Figure 108). Later in the summer they were found mostly below 8 meters depth. At no time were they caught in water warmer than 19°C. The gill net samples may give a distorted picture however, because of small sample size. Only thirty-two 1969 stocked RBT and nineteen 1964-65 stocked RBT were caught during 1969. This low capture rate is partly due to the small size of the 1969 stocked fish and small population size of the 1964-65 RBT. The 1969 stocked RBT averaged 188 mm when stocked, but fish less than 200 mm were seldom caught in the nets. Only 10% of the 1969 stocked fish were 200 mm or larger when stocked. Section Four fish have always had very slow growth and few attained

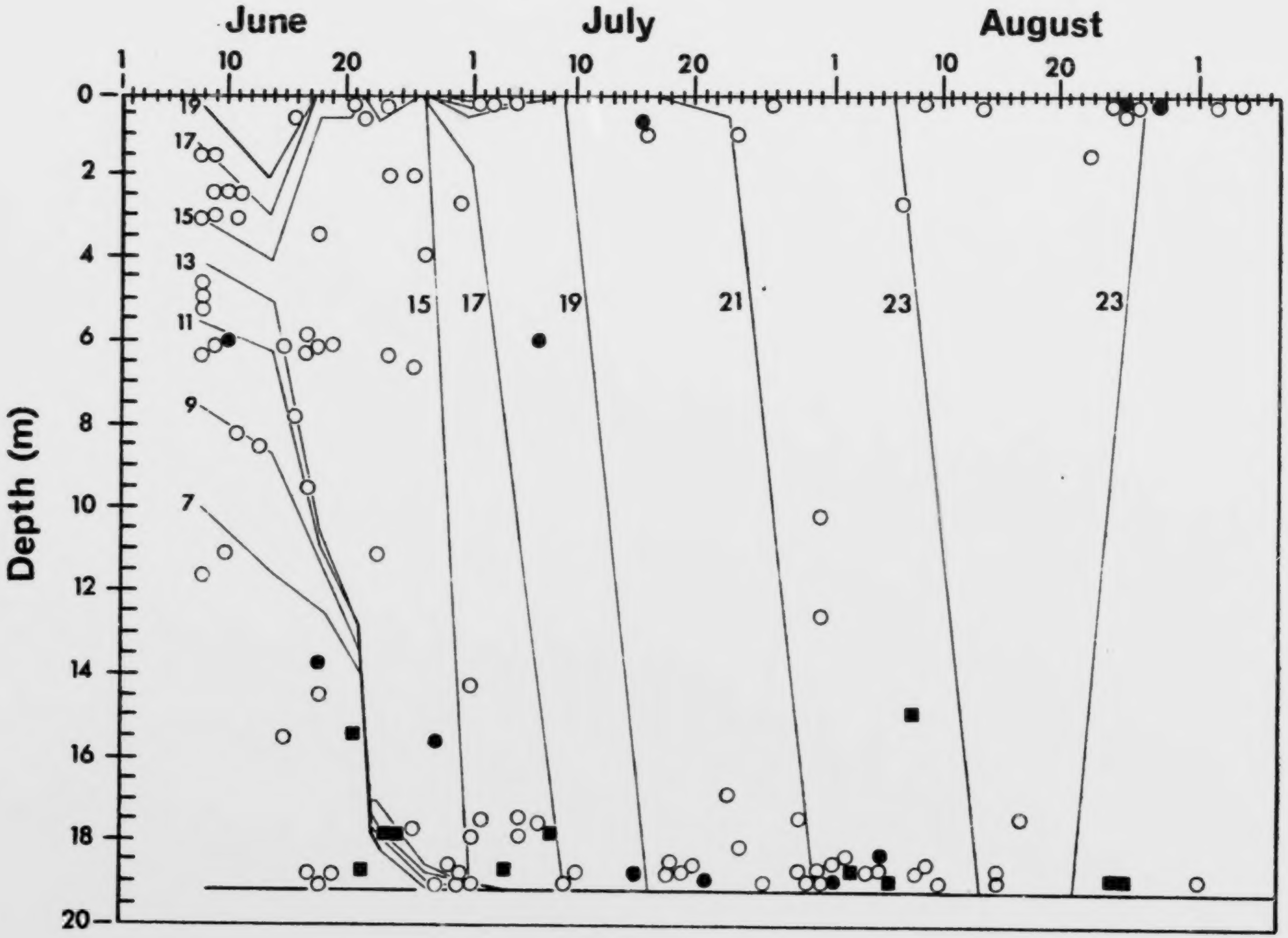
Figure 108. Section Four rainbow trout depth distributions during 1969. Open squares represent fish stocked during June 1969 and marked with a right-pectoral fin clip. Solid squares are fish stocked during 1964-65 and lack fin clips. Each square represents one fish.


June
July
August
10
20
1
10
20
1
10
20
1
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
15
13
11
9
7
17
19
21
23
23

net vulnerable size during 1969. The clear water of Section Four Lake also contributed to low catch rates.

During early June 1970, the rainbow trout were mostly distributed between the surface and 12 meters (Figure 109). Soon after aeration began they distributed throughout the lake. By early July they were mostly distributed along the bottom of the lake. Ninety-four 1970 stocked RBT, eleven 1969 stocked RBT and eleven 1964-65 stocked RBT were captured during 1970. The increased capture rate of the 1970 stocked fish is attributed to their larger size; they averaged 200 mm when stocked.

Figure 109. Section Four rainbow trout depth distribution during 1970. Open circles represent fish stocked during May 1970 and marked with a left-pelvic fin clip. Solid circles represend fish stocked during June 1969 and marked with a right-pectoral fin clip. Solid squares represent fish stocked during 1964-65 and lack fin clips. Each symbol represents one fish.


June
July
August
1
10
20
1
10
20
1
10
20
1
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
19
17
15
13
11
9
7
15
17
19
21
23
23

DISCUSSION AND CONCLUSIONS

Physical-Chemical Parameters

As discussed earlier, a lake's oxygen and temperature regimes are its most important parameters. In Section Four, oxygen concentrations were generally quite high and presented no biotic distributional barrier. In fact, oligochaetes and midge larvae were most abundant in the profundal zone. Temperature exerted a greater influence than oxygen. Artificial destratification greatly altered the temperature regime in Section Four Lake. Although the maximum average temperature was increased 3.6°C by destratification, maximum bottom temperatures were increased more than 15.3°C. Since the dominant biota live in the profundal zone, this represents a very significant alteration of their environment. Many metabolic and other chemical processes double for every 10°C increase. This sort of temperature change could lead to changes in species composition, growth rates, reproductive patterns and distribution within the lake. When temperature is no longer an important barrier, the organisms should distribute according to other conditions such as substrate, light, plankton, rooted aquatic plants and predator-prey relationships. Certain coldwater species may be eliminated from the lake because of the absence of cold, aerated water during the summer. I had expected this sort of problem with the rainbow trout, but it did not occur. However, this could be a serious consequence of destratifying oligotrophic lakes that normally have greater surface temperatures than Section Four.

I did not expect any great changes in the chemical conditions in Section Four as a consequence of destratification. Changes did occur, but they were generally not as striking as when eutrophic lakes are destratified (Fast, 1968). Oligotrophic lakes are typified by their chemical homogeneity. Since the water chemistry did not appear to limit the biotas' distribution before aeration, we should not expect much distributional change in the biota in response to changes in the water chemistry after destratification.

The thermal profiles and thermal stability values indicate the lake was nearly isothermal after June 20, 1970. Slight temperature gradients often occurred at the surface as it was warmed faster than the heat could be redistributed throughout the lake. During periods of intense heating, it is difficult to prevent this thermal microstratification. This is due in part to the fact that the relationship between rate of destratification with constant air input is not linear. The closer thermal stability is to zero, the greater the energy required to cause a unit decrease in thermal stability. It may require relatively little energy to reduce thermal stability by 75%, but much more energy to reduce it to zero.

The destratification system used in Section Four was much larger than necessary. This situation was purposely arranged to assure complete mixing. As in Hemlock Lake, the important factor was measuring the effects of this system of mixing on the biota. We did not want to measure the effects of partial mixing, but of complete destratification. The proper size compressor, distribution and duration of air input, etc. is basically an engineering problem, and one that has not yet been adequately solved.

There were large changes in dissolved organic matter and particulate organic matter. DOM changes may be related to changes in primary production. These changes will be discussed later in greater detail by R. G. Wetzel.

As with Hemlock Lake, phosphorus concentrations were measured only during 1969. They were not continued for the reasons given. Because of the oligotrophic condition of Section Four, I expected even less measurable changes in phosphorus concentrations than we expected in Hemlock. Phosphorus concentrations before aeration were quite variable and low.

There is usually not much economic incentive to artificially destratify an oligotrophic lake. In fact this is the only case that I am familiar with. Destratification is usually instigated to improve water quality by oxidizing and otherwise eliminating anoxic conditions. This is not the case with oligotrophic lakes. The major reason oligotrophic lakes may be destratified is to reduce evaporation rates. This is also an important reason for destratifying eutrophic lakes. Destratification may reduce annual evaporation by 4 to 10 percent (Koberg, 1964, personal communications). This is accomplished by a slight reduction in surface temperatures during the summer. Surface temperatures are slightly warmer during the cooling period, but the periods of above-normal and below-normal surface temperatures are such that a net evaporation reduction is realized. Although the lake's heat budget is greatly increased by destratification, this extra heat is lost to a greater extent by infra-red radiation from the lake, than by evaporation. Reduced evaporation rates can result in a substantial savings. An estimated $10,000 worth of water was saved from evaporation during one year's destratification of El Capitan Reservoir, California (Fast, 1968). The annual cost of running the compressor, amortization of initial investment and maintenance was only about $3,000. These savings are most important, and most likely, in water-starved regions such as our American southwest. Water is in short supply, expensive, and evaporation rates are high.

Primary Production

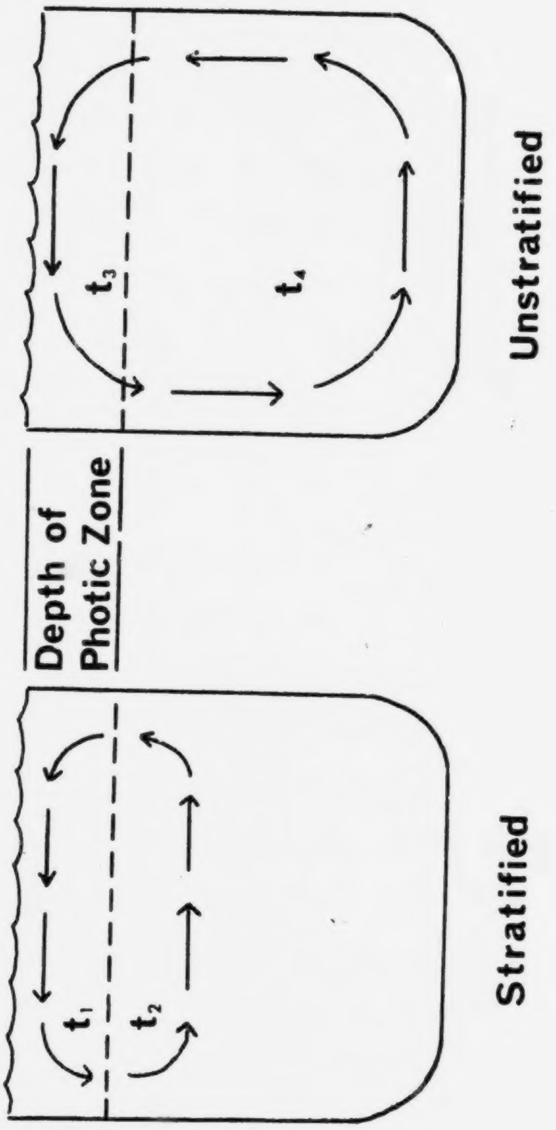
Because of Section Four's oligotrophic condition and marl deposition, I did not expect much change in primary productivity during destratification. Although I expected profundal sediment temperature increases to regenerate some nutrients, I expected these nutrients to be readily bound by the carbonate complexes and therefore effectively unavailable for plant growth.

The evidence indicates that this did not occur. Surface primary production potentials were about three times as great during August 1970 compared to August 1969, and production efficiencies were likewise increased from 1 mgC/m^3/4 hrs/ In cells during August 1969 to between 3 and 4 mg during August 1970. These changes strongly suggest that nutrients were more available following aeration. However, as discussed for Hemlock Lake, other factors could also account for these apparent increases.

Although production potentials and efficiencies increased following aeration, phytoplankton standing crop did not. Average surface values were actually lower during 1970 compared to 1969. Zooplankton grazing could be flaunted as a possible explanation for lower standing crops, but I feel that was not the case. I believe that increased mixing rates and increased mixing volume caused the reductions in standing crop. This mixing in effect prevented the phytoplankton from realizing their growth potential.

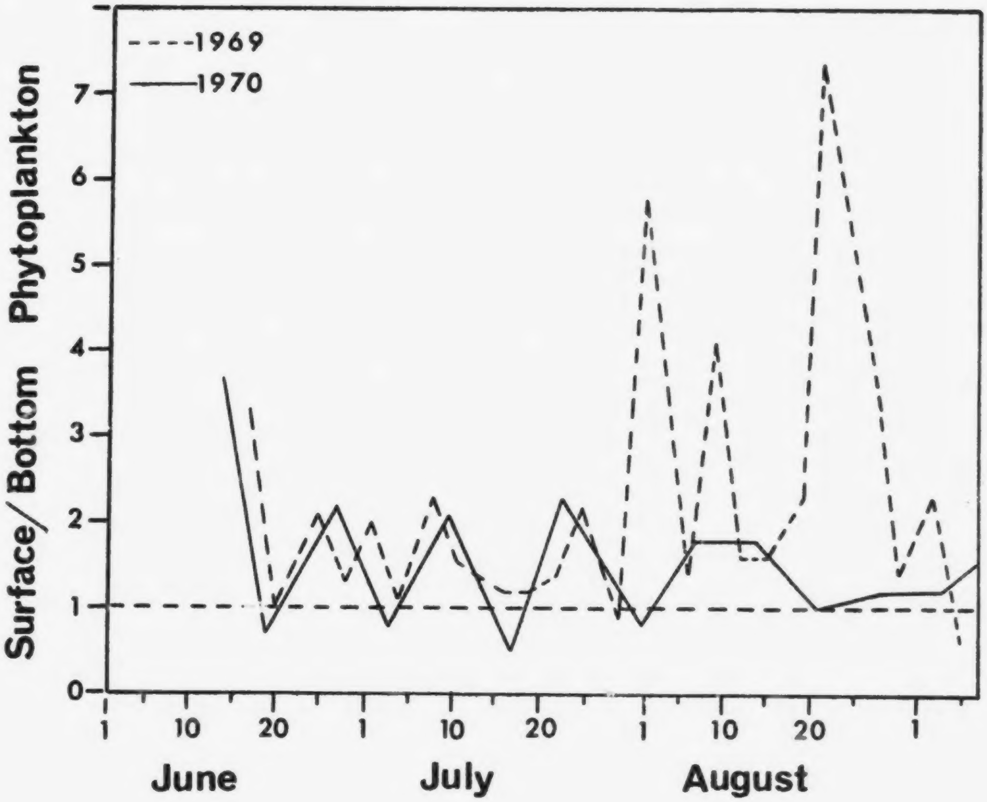
During normal, stratified periods phytoplankters may spend most or all of their time within the photic zone (Figure 110). The ratio t_1/t_2 is relatively large and

Figure 110. Hypothetical residence times for a passive, neutral buoyancy object with the photic and aphotic zones of a stratified and unstratified lake.


Stratified
Depth of Photic Zone
Unstratified
t_1
t_2
t_3
t_4

approaches infinity where t_2 is small. This latter situation probably occurs in a thermally stratified Section Four because of its clarity. About 20% of the surface irradiance was still present at 12 meters on August 11, 1969 when the Secchi was 10.25 m (Figure 82). Although the entire lake may lie within the photic zone, light intensity and production rates are very low in deep water. After destratification, phytoplankters were transported into the deep water to a greater extent than under stratified conditions (Figure 111). Surface/15 meter phytoplankton density ratios average 2.2 during 1969, whereas surface/16 meter densities averaged 1.5 during 1970. This indicates a more even distribution during 1970 compared to 1969 and a shift in densities from the surface to deep water. A 1.0 ratio indicates equal densities at both depths. Ratios above 1.0 represent higher densities at the surface, and ratios less than 1.0 represent higher bottom densities. Densities were always greater at the surface both years, and quite variable from day to day. Bottom densities were greater than surface densities in only 2 of 24 sample sets during 1970. These data indicate that this system of artificial mixing redistributed a significant portion of the phytoplankton population into deeper water. Time spent in the aphotic, or at least dimly lit deep water (t_4) was much increased relative to time spent at shallow depths (t_3). Thus the time available for high production was reduced ($t_3/t_4 < t_1/t_2$) by destratification. Increased

Figure 111. Ratios of Section Four surface/bottom phytoplankton concentrations during 1969 and 1970. The lake was destratified during 1970.



Surface/ Bottom Phytoplankton
- - - -1969
——1970
0
1
2
3
4
5
6
7
1
10
20
1
10
20
1
10
20
1
June
July
August

nutrient availability was not adequate to compensate for these changes and net in situ production decreased. The above conditions are likely to occur in relatively deep, oligotrophic lakes with a large hypolimnetic volume and nearly complete destratification. If destratification is not complete, but stratification persists near the surface, production rates may remain the same or be increased. I observed increased primary production rates in El Capitan Reservoir, California following incomplete destratification. Even with continuous air injection, the eutrophic reservoir typically had microstratification of 2 to 3°C within the upper few meters (unpublished data), and almost all of the primary production occurred within this region. Phytoplankton were apparently kept within this zone, and not swept into the dimly lit regions of the reservoir in sufficient quantity to greatly reduce their population. This stratification was almost always present during the yearly heating cycle and developed because the heat input from solar irradiance was greater than could be distributed throughout the reservoir by the aeration system. This condition almost never developed in Section Four Lake because mixing was almost complete. The air input was actually greater than necessary to assure a thorough mix.

Murphy (1962) hypothesized that increased mixing depths and/or turbidity acting alone would reduce primary production. His hypothesis predicts that increased mixing depths and turbidity such as occurred in Section Four during complete destratification would lead to decreased primary production, and that decreased mixing depths such as occurred in El Capitan Reservoir during incomplete destratification would lead to increased production rates. His predictions in these two cases agree with observations. Likewise his calculated production rates agreed well with those he observed in 33 shallow California ponds. He suggests manipulating reservoir production rates by adjusting metalimnion depths. Decreased metalimnion depths could be achieved by epilimnion withdrawals or incomplete destratification, whereas increased metalimnion depths could be achieved by hypolimnion withdrawals or air injection at some desired depth which is less than maximum depth. Hooper et al. (1952) increased the metalimnion depth by mixing hypolimnion water with epilimnetic. This increased phytoplankton and periphyton production because the hypolimnion was nutrient-rich relative to surface waters. This nutrient increase more than compensated for possible increased mixing depths.

Knoppert et al. (1970) found they could increase the metalimnion depth by air injection at some intermediate depth. Their metalimnion usually began at about 5 meters, but was lowered to the air input level of 19 m within three weeks. Maximum depth was over 27 m, but water below 19 m was not upwelled by their aerator and a sharp thermal discontinuity developed at 19 meters. Knoppert et al. conducted another experiment to determine the effect of increased mixing on plankton populations. They increased the mixing rate of two shallow reservoirs without altering their thermal regimes. These reservoirs did not normally stratify thermally, but they had reduced photic zones. Their results were inconclusive, but suggest that increased mixing alone did not greatly affect the phytoplankton.

Robinson et al. (1969) evaluated the effects of intermittent destratification on two northern Kentucky reservoirs. Total phytoplankton standing crops in these destratified lakes responded about the same as those in a control lake. They concluded, however, that bluegreen algae declined faster than green algae and the number of plankton species remained the same or increased slightly following air injection. Bernhardt (1967) also reports a decline in the bluegreen algae *Oscillatoria rubescens* during artificial destratification of eutrophic Wahnback Reservoir, Germany. *Melosira granulata angustissima* became abundant after *O. rubescens* disappeared. Bluegreen algae were not conspicuous in Section Four either before or during destratification. Most significantly, Bernhardt also found "... there was no increased bioproduction," due to artificial destratification. Artificial destratification was incomplete since a small thermal gradient persisted near the surface part of the summer. This condition is similar to that discussed for El Capitan Reservoir, California.

I am uncertain how to interpret periphyton events. In contrast to the phytoplankton, they were not swept out of the surface waters by the currents. Increased turbidity could have deleteriously affected their growth, but increased nutrient availability should have promoted periphyton growth. Likewise, increased water currents due to air injection should have favored periphyton growth. Short-term periphyton accumulations do show significant increases, but the long-term accumulations are about the same both years. This suggests that colonization and the early "successional" stages were accelerated by destratification but the maximum accumulation levels were not affected. In contrast, both short-term and long-term periphyton accumulations were increased in Hemlock Lake. I have no good suggestions to explain these differences in Section Four Lake.

Zoobenthos

The most obvious response to the Section Four zoobenthos to destratification appears to be a reduction in numeric and biomass standing crops. Oligochaetes (microdriles) and Chironomid larvae had especially large reductions in standing crop as well as average sizes during 1970 (Table 8). All organisms except the Oligochaete megadriles, Chironomid pupae and Odonates were smaller during 1970, and all the minor species, except the Heleids were numerically more abundant during 1970.

Although reduction in oligochaete standing crop appears directly related to destratification, Chironomid standing crop reduction could be due to emergence. Midge emergence during the summer 1969 was closely related to periods of rapid heating. The spring 1970 temperatures appear to have been warmer than during the spring 1969. For example, the early June 1970 surface temperature was 19.5°C compared to 16°C the previous June. These higher temperatures could have promoted a greater emergence rate prior to my sampling and resulted in lower standing crops during June 1970. This could account for lower standing crops during June 1970, but not necessarily during the remainder of the summer since reproduction and growth should have occurred.

The most likely explanation for the observed zoobenthos reductions in standing crop is that destratification resulted in a reduction, or at best no change in primary production and an increased heat budget. The surface phytoplankton standing crop appears less concentrated during most of the summer 1970 (Figure 82), and total accumulated periphyton was about the same both years. Total phytoplankton standing crop may actually have been greater during 1970 than during 1969 since aeration could have distributed it more uniformly throughout the lake; but this cannot be accurately demonstrated from the data. In any case, phytoplankton surface concentrations were less during 1970. An increased heat budget should have resulted in greatly accelerated metabolic rates for certain organisms such as the oligochaetes.

Almost all of the oligochaetes and a large percent of the Chironomid larvae were found below 14 meters both years. These deep-dwelling individuals experience maximum temperature increases of about 15°C due to destratification. Many biochemical reactions were doubled by every 10°C temperature increase. Increased catabolic rates without a commensurate increase in anabolism should result in decreased biomass, as observed. Put more simply, respiration was increased by temperature increases, but synthesis either remained the same or decreased due to an unchanged or decreased food supply. The net result was "negative growth," i.e., a decrease in standing crop. If we agree that this is deleterious, then we could say that artificial destratification of Section Four caused thermal pollution of the lake, although the results were not obvious to the casual observer.

Unlike Hemlock Lake, the Section Four's sediments were well oxidized and contained sparse organic matter prior to artificial aeration (Figure 14). Oxygen concentrations were always high over the sediments and decomposition was probably almost complete. Aerobic decomposer microbes, as well as larger detritivores undoubtedly worked over these sediments to a large degree. Consequently, destratification probably did not greatly affect nutrient regeneration from, or decomposition of, these sediments. The availability of organic debris to the zoobenthos was probably likewise unchanged by destratification. These conditions differ greatly from the profundal conditions of eutrophic lakes where decomposition is retarded by anaerobiosis and organic debris is unavailable to the detritivores for long periods.

Reductions in average sizes of most organisms during 1970 is most puzzling. It is generally agreed that smaller organisms have greater metabolic rates. If this is true of aquatic invertebrates, and the aforementioned changes occurred in the metabolic rates, then I would expect larger species or individuals to be favored during destratified periods. In fact, this does not appear to be the case.

Although production rates were not measured for any species, midge emergence may be considered a rough estimate of midge production. The reduction in total emergence suggests that total midge production was decreased by destratification. Production per individual may have actually increased, however, since total midge emergence decreased 10% between 1969 and 1970, but number of midge larvae collected decreased 54% during these same periods.

I was surprised by the almost indiscernible effect of destratification on the zoobenthos depth distributions. Midge pupae and emergence depth distributions were most affected, but not as much as expected. Although oxygen and presumably most other chemical parameters were not limiting, I expected temperature to represent a real barrier to certain organisms (e.g., see discussions of fish and crayfish depth distributions). I had expected a net movement of Chironomids, mayflies, amphipods and possibly other taxa into deep water and a net movement of oligochaetes into shallow water. The absence of these changes suggests that other conditions such as sediment conditions, attached vegetation, and light are more important factors. Oligochaetes were almost entirely limited to shallow water by anoxia in eutrophic El Capitan Reservoir, California (Fast, unpublished data). When this lake was destratified the oligochaetes distributed evenly throughout the entire lake even though large differences existed between sediment conditions at different depths and at different points in the lake (Fast, 1968). I had expected a similar net movement of oligochaetes into shallow water after Section Four was mixed, but only a few individuals moved into, or remained in shallow water after destratification.

Crayfish

Factors influencing *Orconectes virilis* depth distributions within lakes are not well understood. Momot (1967) and Momot and Gowing (1970) found that both sexes of *O. virilis*, in nearby lakes were mostly found in shallow water during May and June. Adult females moved to deeper water first, followed by young females and males as they reached sexual maturity. By August 70% of the adult females were below 6.0 m and were concentrated at 7.6 m. During this same period, 65% of the yearling males and females were between 3.0 m and 6.0 m, while over 85% of the adult males were above 6.0 m. The lowermost extent of the metalimnion during August was 9.1 m with a 13°C temperature. Oxygen and other chemical concentrations were not presented. The crayfishes' maximum depth distribution coincided with the bottom of the metalimnion. These authors feel that the migration to deeper water is related to sexual maturation. Aiken (1968) also showed that mature O. virilis in an Alberta, Canada stream also moved to deeper water in late summer. The females preceded the males. (This migration contributed to overwinter survival of the species.) He also believes the migration is related to sexual maturation since maturation is related to photoperiodism and temperature (Aiken, 1969).

Section Four O. virilis depth distributions during 1969 coincide well with those described by Momot (1967) and Momot and Gowing (1970). During August the males were in shallow water and the females were much deeper. By June 1970, both sexes were concentrated in shallow water. Both seasons their lowermost limit was related to the 10°C isotherm and not other chemical factors. However, almost immediately after aeration began during June 1970, both sexes distributed throughout the lake. Although they were not aged, there was no conspicuous size distribution of either sex as a function of depth. By early July and thereafter, the males always had a greater average depth than the females. Both sexes were about evenly distributed throughout the lake after destratification. This even distribution seems to mitigate against the sexual maturation hypothesis. If light intensity is important for maturation, then the mature females and recently mature males and females still should have preferred, and concentrated in, deep water. The mature males distribution should have remained about the same. If cold water is the important factor affecting their depth selection, then an even distribution of the females could be expected; since the lake was isothermal, they should have randomly searched for cold water. This does not necessarily explain the even distribution of the mature males, however, since the surface temperatures were about as warm as during the preceding summer. If the males were independent of temperature above 10°C, then their distribution should have been about the same both years.

I would like to suggest that O. virilis depth distributions are not directly related to maturation, but when other factors such as oxygen are not limiting, mostly to water temperature, social aggression of the mature male, and maturation of the mature female and yearlings. The mature males are highly aggressive and are known to repel the smaller males and females (Abrahamsson, 1966; Camougis and Hichar, 1959). These authors also suggest that the adult males concentrate in shallow water because this zone offered the best conditions for food and shelter. I suggest that the mature males usually select shallow water because this is the zone with the highest temperature. Although O. virilis functions above 10°C (Momot, 1967) its metabolism should increase as a function of acclimation temperature. If increased metabolic rate is advantageous, then the crayfish should seek warmer waters. Not all individuals successfully inhabit the warmer water, however, since the mature males repel the weaker, less aggressive females and yearlings into deeper, colder water. Bovbjerg (1964) found that both O. virilis and O. immunis prefer the same substrate when tested separately. When tested together O. virilis drove O. immunis from the preferred substrate, again attesting to the highly aggressive behavior of O. virilis. Bovbjerg also found that the dispersion rate of another crayfish, Cambarus alleni was density dependent. High density dispersion rates were more than twice as great as low density rates. Repulsion of female by male O. virilis could account in part for slower growth rates and survival of females. Cannibalism of females by males also partly accounts for decreased female survival. The foregoing discussion explains the late summer distribution, but not the early summer distribution. In early summer all individuals are found in shallow water. This could be explained in part by behavior related both to water temperatures and sexual maturation. During May and June water temperatures are much lower than during August. If social aggression by mature males is partly related to water temperatures, they will be less inclined to repel other individuals during this period. This is important for the survival of the species. If growth and molting is also related to temperature, it is important that mature females and yearlings remain in shallow, warm water as long as possible. This will assure development of the eggs and maturation of yearlings. Once these functions are complete, it may be immaterial where these members spend the rest of the summer, as long as there are enough available for breeding and reproduction the following year. The newborn have mostly left the mature females by June. This is when the mature females migrate to deeper waters, or are driven there by the males. The yearlings move into deeper water somewhat later than the mature females. This exposes them to predation by the mature males for a longer period, but not during the warmest part of the summer. The advantages of remaining in the shallow, warm water to mature may outweigh the detrimental influence of the mature males.

Artificial destratification greatly altered the usual distribution patterns. Since the lake was isothermal, there was no longer any advantage to select shallow depths. The water was about the same temperature at all depths and all individuals were exposed to similar thermal conditions. Under this situation, the mature males no longer selected the shallow depths, but distributed more or less evenly throughout the lake. Several authors have shown that crayfish either have a very large home range or none at all

(Abrahamsson, 1966; Hichar and Camougis, 1959; Penn, 1950) and travel great distances in a short period. During stratified periods, they moved randomly about the shallow depths, limited by the cold temperature of the lower depths and by the shore. After destratification, individuals undoubtedly wander throughout the entire lake. During August 1970, the entire lake was about as warm as the surface waters were during 1969. I would therefore expect similar behavioral activities and metabolic rates of the mature males at all depths. The effect of this on the females and yearlings is unknown. Also unknown is the effect of increased temperature on the maturation and metabolism of the females and yearlings. Increased metabolism may have permitted them to better cope with the aggressive males. Decreased densities following dispersal should also have lowered encounter rates. If destratification were continued several years, densities of mature males throughout the lake might approach former shallow water densities and lead to low survival of females and young crayfish.

If repulsion of females is the important factor affecting their distribution during late summer, then evidence should exist for this both years. The correlation between male and female depth distributions during August 1969 was -0.29 (F= 0.76, d.f.= 8). During August and September 1970, when the lake was isothermal, the correlation was -0.52 (F= 1.89, d.f.= 5). Although neither correlation is significant at the 0.05 level, they are indicative. In both cases low concentrations of females were associated with high concentrations of males. During 1969 the males were most abundant in shallow water, but during 1970 they were most abundant in deep water. This evidence is rather weak and indirect, but tends to substantiate the general hypothesis.

Another, somewhat overlooked possibility exists to explain the observed distributions. If the much touted aggressive behavior of the male does greatly affect the behavior of the female and yearlings, it is also possible that this factor alone determines the distribution of females and yearlings within traps. If male aggression can be credited for altering the preferred distribution of other individuals within the lake, it seems logical that this aggression could also affect their distribution within the traps. Traps with many mature males usually contain few females or young crayfish. Is this because the latter are not present in that area, or because they are driven from or do not enter the trap? If the actual distribution of females was exactly the same as the males at all times, but the females avoided high concentrations of males, such as in certain traps, then we would observe distributions such as those discussed. Likewise, the sex ratio would on the average be in favor of the males and female catch rates would be much lower. These conditions are also universally observed with O. virilis.

Rainbow Trout

During 1969, the Section Four rainbow trout ranged between the 5°C and 19°C isotherms (Figure 108). They exhibit no preference for the 13°C final preferendum temperature indicated by Garside and Tait (1958). Garside and Tait conducted their laboratory experiments with 100 mm to 150 mm length fish. Although light (Sullivan and Fisher, 1953; Brett, 1952; Pearson, 1952), feeding activity (Brett, 1952; Pearson, 1952) and social behavior (Pearson, 1952) are known to affect fishes' temperature selection, it is uncertain what the major factor was in Section Four. These fish had very slow growth rates. Their stomachs were usually empty when captured. The usual stomach contents included periphyton, sticks, marl encrustaceons, miscellaneous detritus, terrestrial insects, amphipods and cladocera. No food item predominated. The nature of their diet and slow growth indicate they were at near starvation levels. The 1954-65 stocked trout were very emaciated. These conditions could lead to a general "search" behavior and thus account in part for their scattered distribution. This distribution is in contrast to that found by Horak and Tanner (1964) in Horsetooth reservoir. Horsetooth Reservoir is also oligotrophic. As in Section Four, oxygen, pH, carbon dioxide and alkalinity gradients apparently did not present barriers to the rainbow trouts' depth distribution. Nevertheless, the Horsetooth Reservoir trout preferred water between 18.9°C and 21.1°C.

Over 93% were found in or above the metalimnion. The predominant factor affecting their distribution in Horsetooth Reservoir appeared to be food distribution. The trout predominantly fed on cladocera, and cladocera were most abundant in the epilimnion. We did not measure cladocera depth distribution in Section Four, but trout food analysis indicates they were not a major item.

The intensity of the thermal gradient could be an important factor. In Section Four this gradient was relatively weak. This is typical of sheltered lakes. Using a definition of the metalimnion as a change of 1°C/m depth increase, the metalimnion begins at the surface on some dates (Figure 72) and extended to near the bottom. Although no one has clearly described rainbow trout responses to different temperature gradients, other organisms react abruptly to strong thermal gradients. Beeton (1960) found that vertically migrating Lake Michigan Mysis relica would not penetrate a thermal gradient of 1.67°C to 2.0°C/m, but some temporarily penetrated a 0.66°C to 0.94°C/m gradient. During isothermal periods they would migrate uninterrupted from the bottom to the surface. Harder (1968) found many marine zooplankters reacted to discontinuities in stratified laboratory cylinders. These discontinuities included density gradients due to temperature, salinity and density without temperature and salinity gradients. Burbige (1969) found that American smelt (Osmerus mordax) would not penetrate strong thermal gradients in the metalimnion.

Although trout were not captured near the surface after early July 1969, they were seen to feed at the surface after that period. Likewise, terrestrial insects and surface living insects were found in their stomachs. This indicates that they avoided prolonged periods in shallow water. They appeared to reside mostly in the deeper water with feeding excursions into shallow water. Because of the water clarity, they could undoubtedly see surface disturbances from some depth.

I was especially interested in the effects of artificial destratification on the survival and distribution of the trout. Since artificial destratification increases the lake's heat budget, and eliminates the deep, cold water, this poses a threat to the trout (Fast, 1968; Fast and St. Amant, in preparation). Although trout can withstand 26.7°C temperatures for a few days, prolonged temperatures above 24°C lead to high mortalities (Eipper, 1960). During a summer of continued aeration the entire lake will become about as warm as the surface waters during a summer of normal stratification. If the surface waters normally attain 26°C or more during the summer, the entire lake may become this warm. Normally Section Four's maximum epilimnetic temperature is between 23°C and 25°C. With continuous air injection during 1970, the entire lake was over 23°C for about two weeks during August. No trout mortalities were observed during this period, nor did the fish appear otherwise adversely affected.

The temperature increase apparently was not great enough to be detrimental.

Although they were distributed throughout the lake during artificial destratification, they showed a preference for the bottom. Before aeration began during early June, they were found mostly between 1 and 12 meters, but soon after aeration began, they were most abundant in the 17 to 19.6 meter interval. Food does not appear to be an important factor affecting this distribution, since their diet was essentially the same as during 1969. It could be a thwarted attempt to seek cooler water, since before aeration cooler water could be found by swimming downwards.

Many trout concentrated in the rising air bubbles. Fast (1971) describes this same response of threadfin shad (Dorosoma petenense) in a southern California reservoir. In the shad case, their aggregation was thought to be a rheotactic response which was reinforced, or rewarded, by high food concentrations in the rising water. If zooplankton concentrated along the bottom of Section Four, this rising water undoubtedly contained higher concentrations than the surface waters. Trout aggregated in the rising water might thus be exposed to higher food concentrations than other surface-dwelling trout.

From the fisheries standpoint, artificial destratification of oligotrophic lakes is generally not advisable, since such mixing will increase their heat budgets and eliminate the lakes' cold water. Such heating can lead to the elimination of coldwater species such as trout. Oligothrophic lakes with borderline surface temperatures, such as Section Four, are possible exceptions. Destratification of these lakes may increase fish food and trout production. There is no evidence that artificial destratification of Section Four was either beneficial or detrimental for the rainbow trout. No obvious increase in mortality was observed, nor did their growth or general condition appear to improve.

AERATION TO PREVENT WINTERKILL

Winterkill conditions often develop in small eutrophic lakes subject to extensive periods of ice and snow cover (Greenbank, 1945; Cooper and Washburn, 1946). These lakes are typically shallow with a high BOD. The ice cover prevents absorption of atmospheric oxygen, while the snow cover limits photosynthetic oxygen production. As a consequence, oxygen may be depleted below concentrations necessary for fish and other biota and mass mortalities occur.

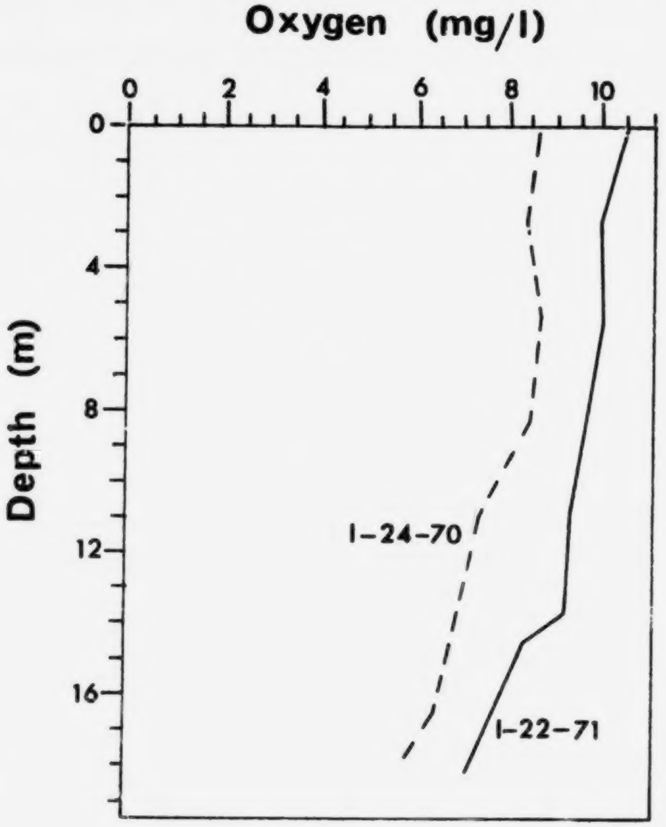
There are basically two solutions to the winterkill problem: (1) Snow removal to promote photosynthesis. This procedure should be started early and continued most of the winter; and (2) Artificial aeration of the water. Several techniques for artificial aeration have been developed. Merna (1965) and Flick (1968) pumped water onto the ice and allowed it to drain back into the lake through holes chopped in the ice. This procedure melted the snow cover and increased oxygen concentrations within the lake to acceptable levels. Rasmussen (1960) and Wood (1961) injected air under the ice from perforated air lines. This technique melted large areas of the ice cover and greatly increased the oxygen concentrations. Patriarche (1961) unsuccessfully used a perforated air line system in a shallow southern Michigan lake. His system circulated the water over high BOD sediments which removed oxygen from the water. His air input was not great enough to compensate for this loss and the total oxygen content decreased. Halsey (1968) effectively prevented winterkill conditions by artificially aerating before an ice cover formed. His lake usually did not thoroughly mix following the fall overturn. Consequently, oxygen concentrations, especially in deep water, were low when ice covered the lake. Snow cover compounded this situation and led to near zero oxygen concentrations by spring. By aerating before ice formed, he raised oxygen concentrations throughout the lake to near saturation, oxidized much of the organic matter and thus prevented oxygen depletion.

As part of my study, I was especially interested in what effect summertime aeration has on winter oxygen concentrations. As we have seen, primary production and plant standing crops were greatly increased in both Hemlock and Section Four Lakes by aeration. These materials use oxygen when they decompose and could contribute to winterkill conditions. Tanner (1952) greatly reduced winter oxygen concentrations in these two lakes by summertime artificial fertilization. Fertilization increased primary production and the rate of oxygen consumption. Both summer and winter oxygen concentrations were greatly reduced by this practice. During the winter following fertilization, the depth where oxygen fell below 2.0 mg/l decreased from 6.8 to 3.4 meters in Hemlock lake, and from over 15 meters to 1.2 meters in Section Four Lake. Ball (1948) also reports the winterkill of fish and invertebrates following artificial fertilization. Ball used much higher fertilizer concentrations and thereby produced anaerobic conditions throughout the entire lake during the winter.

After a summer of normal stratification Section Four had more than 5 mg/l at all levels on January 24, 1970 (Figure 112). About 37 cm of powdery snow and 31 cm of ice covered the lake. This much snow reduced light penetration by more than 99%. The dates of ice cover formation are not known, but were thought to be during early December both winters. Winter oxygen concentrations were greatly reduced following fertilization in 1949 and 1950. Most of the lake had less than 2.0 mg/l by February 26, 1951 (Tanner, 1952). The increased oxygen concentration by 1969 suggests that the effects of fertilization were not long lasting. The nutrients presumably were tied up in the sediments and essentially non-cycling.

On January 22, 1971, following a summer of artificial destratification, Section Four had more than 7.0 mg/l oxygen at all depths. Oxygen concentrations were from 1.0 to 2.0 mg/l greater at all depths than during the previous year. Snow and ice cover were less during January 22, 1971; 19 cm and 16 cm respectively. This indicates that snow and ice

Figure 112. Section Four oxygen profiles during January 1970 and 1971. The 1970 profile is after a summer of normal stratification, while the 1971 profile is after a summer of artificial aeration.

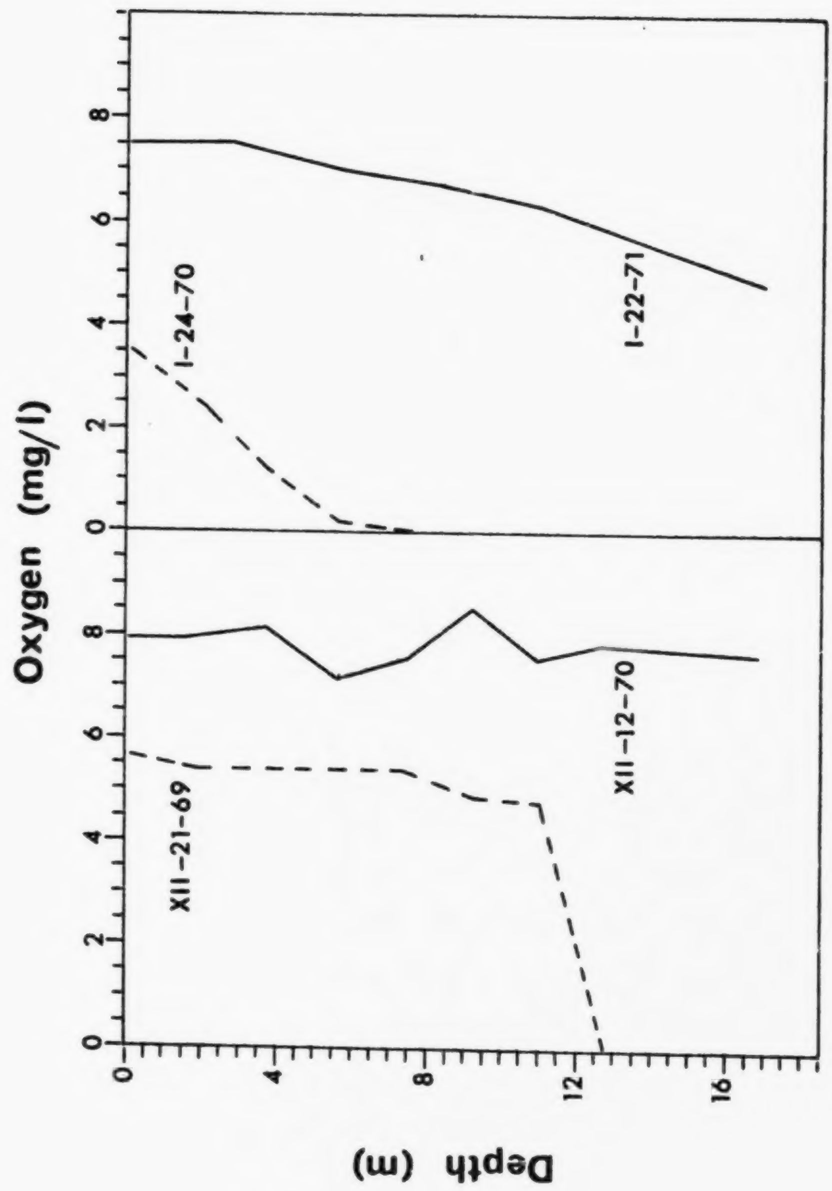

Oxygen (mg/l)
0
2
4
6
8
10
Depth (m)
0
4
8
12
16
1-24-70
1-22-71

cover was not as great as during the previous year, and could account in part for the higher oxygen concentrations. Nevertheless, the increased productivity during artificial aeration apparently did not deleteriously affect the winter oxygen concentrations. I believe that the decomposition rates were also greatly accelerated by destratification, and the increased plant biomass was more completely oxidized before winter stratification began. Destratification increased the lakes' average summer temperature, as well as oxygen concentration. Both of these conditions should promote rapid decomposition.

Hemlock Lake has a much greater oxygen demand than Section Four. On December 21, 1969, levels above 12 meters were well oxygenated, but no oxygen was observed below 13 meters (Figure 113). Snow and ice cover were 18 cm and 12 cm respectively. By January 24, 1970, no oxygen was present below 8 meters and only 3.5 mg/l were present just under the ice. Snow and ice cover were 37 cm and 31 cm respectively. Conditions undoubtedly became worse before the spring turnover, but no appreciable winterkill occurred. Many rainbow trout overwintered without any known ill effects.

After a summer of artificial aeration, oxygen levels were much greater at all levels. About 4 cm of ice and scant snow covered Hemlock on December 12, 1970. Oxygen concentrations were about 8.0 mg/l at all levels. This represents a large increase in oxygen content compared to the

Figure 113. Hemlock Lake oxygen profiles during December 1969 and 1970, and January 1970 and 1971. The December 1969-January 1970 profiles are after a summer of normal stratification, while the December 1970-January 1971 profiles are after a summer of artificial aeration.

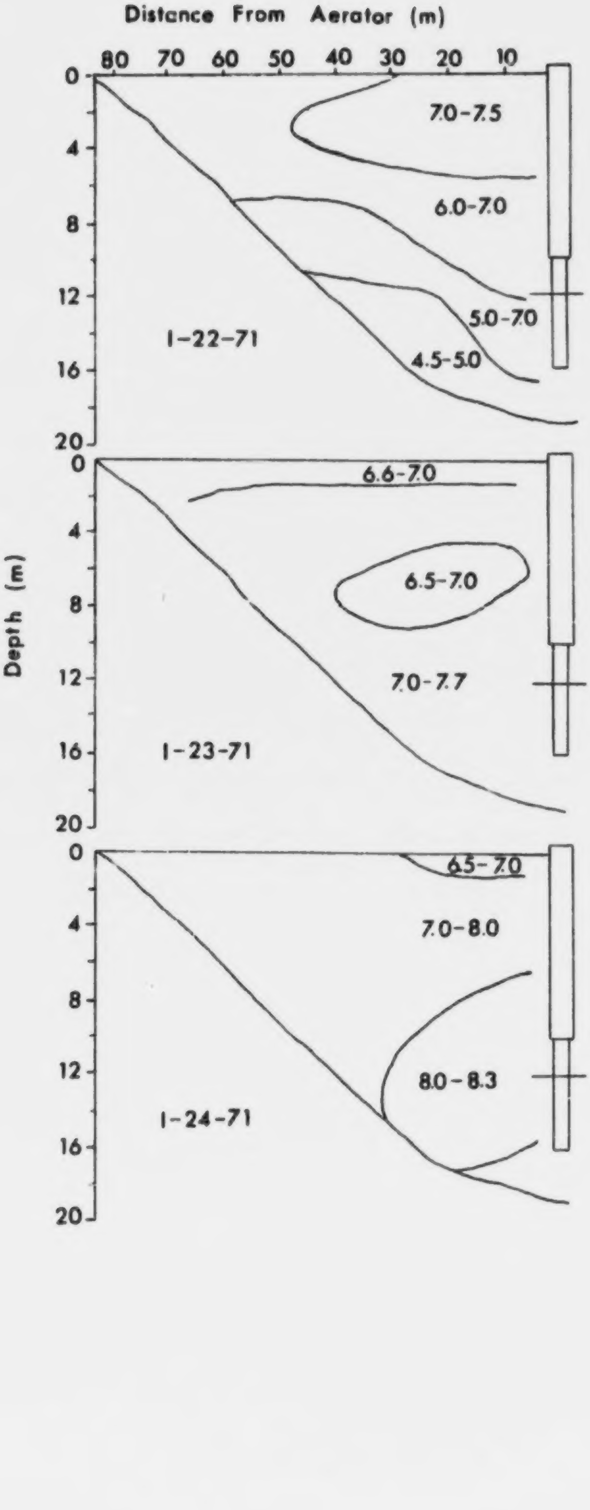

Oxygen (mg/l)
0
2
4
6
8
0
2
4
6
8
Depth (m)
0
4
8
12
16
I-24-70
I-22-71
XII-21-69
XII-12-70

previous winter. By January 22, 1971, oxygen values ranged from 4.5 mg/l at the bottom to 7.5 mg/l at the surface. Snow and ice cover were 15 cm and 25 cm respectively. Although less stringent climatic conditions could account for some of the increased oxygen, they probably do not account for much of it. I attribute this large increase in winter oxygen concentrations to summertime aeration of Hemlock. Although more plant biomass was produced during the summer 1970 compared to the summer 1969, I believe it was more completely decomposed because of the well-aerated conditions. These conditions, plus increased temperatures, permitted more efficient decomposition and oxidation of materials before the onset of winter stratification. The oxygen concentration was not only increased by aeration, but the BOD was undoubtedly lowered by continuous summertime aeration.

After the samples were collected January 22, 1971, I ran the aerator almost continuously for two days (Figure 114). This was done to determine its ability to aerate under the ice. Before aeration began, oxygen concentrations at the lake's center ranged from 4.5 mg/l at the bottom to 7.5 mg/l just under the ice (Figure 115). Oxygen isopleths were not horizontal, indicating nonuniform rates of oxygen consumption and/or convection currents. Oxygen concentrations were above 4.5 mg/l at all locations however. On January 23rd, after 23 hours of air injection, not less than 6.5 mg/l

Figure 114. Artificial aeration of Hemlock Lake during January 1971. The compressor was towed onto the lake and run for two days. A rubber air line leads to the aeration tower.

Figure 115. Effects of artificial aeration on the oxygen regime during January 1971. The January 22nd figure shows the oxygen profiles before winter aeration began, but after a summer of artificial aeration. The January 23rd profile is after 24 hours of air injection and the January 24th profile is after 48 hours of air injection.



Distance From Aerator (m)
80 70 60 50 40 30 20 10
Depth (m)
0 4 8 12 16 20
7.0-7.5
6.0-7.0
5.0-7.0
4.5-5.0
1-22-71
6.6-7.0
6.5-7.0
7.0-7.7
1-23-71
6.5-7.0
7.0-8.0
8.0-8.3
1-24-71

oxygen was present at all locations. A maximum concentration of 7.7 mg/l was observed. Air and water leaked through the tower walls under the ice. After four hours of aeration, the ice was completely melted around the tower. This melted region measured about 20 meters by 10 meters after one day of aeration. The ice was melted from below by upwelled water, since water did not flow onto the surface of the ice.

On January 24th, after about 46 hours of aeration, oxygen concentrations ranged between 6.5 mg/l and 8.3 mg/l. Oxygen concentrations inside the aerator were 9.3 mg/l at the top.

These data indicate that this hypolimnion aerator can be used to aerate under the ice. If it had not leaked air and water through its walls, I would expect the ice around the tower to remain intact and not melt. In most situations it is desirable to prevent melting since open water or weak ice is a hazard. Although the under-the-ice oxygen values were increased substantially, the relative increase would have been even greater if conditions had been comparable to January 1970. Oxygen absorption is much more efficient when the concentration is near zero, than when it is near saturation.

LITERATURE CITED

Abrahamsson, S. A. A. 1966.
Dynamics of an isolated population of the crayfish Astacus astacus Linne. Oikos, 17: 96-107.

Aiken, D. E. 1968.
The crayfish Orconectes virilis: survival in a region with severe winter conditions. Can. J. Zool. 46: 207-211.

Aiken, D. E. 1969.
Photoperiod, indocrinology and the crustacean molt cycle. Science, 164: 149-155.

Allison, L E. and C. D. Moodie. 1965.
Methods of soil analysis, part 2, chemical and microbiological properties. C. A. Black, ed., Amer. Soc. Agronomy, Inc., Madison, Wisc., pp. 1387-1389.

American Public Health Association. 1965.
Standard methods for the examination of water and sewage, 12th ed. Amer. Pub. Health Ass. and Amer. Wat. Wks. Ass. and Wat. Poll. Cont. Fed., New York. 522 pp.

Anderson, R. O. 1959.
A modified flotation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4: 223-225.

Augenfeld, J. M. 1967.
Effects of oxygen deprivation on aquatic midge larvae under natural and laboratory conditions. Physiol. Zool. 40: 149-158.

Ball, R. C. 1948.
Relationship between available fish food, feeding habits of fish and total fish production in a Michigan lake. Mich. St. Coll. Agr. Exp. Sta., Tech. Bull. 206, 38 pp.

Ball, R. C. 1949.
Experimental use of fertilizers in production of fish food organisms and fish. Tech. Bull. 210, Michigan State College Agr. Exp. Sta.

Ball, R. C. and D. W. Hayne. 1952.
Effects of the removal of the fish population on the fish food organisms of a lake. Ecol. 33: 41-48.

Ball, R. C. and H. A. Tanner. 1951.
The biological effects of fertilizer on a warm awter lake. Tech. Bull. 223, Mich. State College Agr. Exp. Sta.

Bardach, J. E. 1955.
Certain biological effects of thermocline shifts. Hydrobiologia, 7: 309-324.

Bardach, J. E. and R. G. Bjorklund. 1957.
The temperature sensitivity of some American freshwater fishes. The Amer. Naturalist. 91: 233-251.

Barnhardt, H. 1967.
Aeration of Wahnback Reservoir without changing the temperature profile. Amer. Wat. Wks. Ass., J., (Aug.): 943-964.

Barrett, P. H. 1952.
Effects of alkalinity on adsorption and regeneration of phosphorus in natural lakes. Ph. D. Thesis, Michigan State College, E. Lansing, Michigan.

Beeton, A. M. 1960.
The vertical migration of Mysis relicta in Lakes Huron and Michigan. J. Fish. Res. Bd. Canada. 17: 517-539.

Black, E. C., E. J Fry and V. Black. 1954.
The influence of CO_2 on the utilization of oxygen by some freshwater fish. Can. J Zool. 32: 408-420.

Borges, H. M. 1950.
Fish distribution studies, Niaugua arm of the Lake of the Ozarks, Missouri. J. Wildlife Manag. 16: 16-23.

Bovbjerg, R. V. 1964.
Dispersal of aquatic animals relative to density. Verh. Internat. Verein. Limnol. 15: 879-884.

Brett, J. R. 1952.
Temperature tolerance in young Pacific salmon, genus Oncorhynehus. J. Fish Res. Bd. Canada, 9: 265-323.

Brook, J. L. and S. I. Dodson. 1965.
Predation, body size and composition of plankton. Science, 150: 28-35.

Brundin, L. 1951.
The relation of O_2-microstratification at the mud surface to the ecology of the profundal bottom fauna. Rept. Inst. Freshwat. Res. Drottingholm, 32: 32-42.

Brundin, L. 1953.
The bottom faunistical lake type system and its application to the southern hemisphere. Moreover a theory of glacial erosion as a factor of productivity in lakes and the oceans. Verh. Internat. Ver. Limnol. 8: 288-297.

Bryce, D. 1965.
Notes on some Chironomidae (Diptera) from acid peat pools. Entomologist 98: 49-53.

Burbige, R. G. 1969.
Age, growth, length-weight relationship, sex ratio and food habits of American smelt, Osmerus mordax (Mitchell) from Gull Lake, Michigan. Trans. Amer. Fish. Soc. 98: 631-640.

Camougis, G. and J. H. Hichar. 1959.
Some studies on crayfish distribution in a small pond. Amer. Midl. Nat., 62: 227-321.

Coffin, C. C., F. R. Hayes, L. H. Jodrey and S. G. Whiteway. 1949.
Exchanges of materials in a lake as studied by the addition of radioactive phosphorus. Canad. J. Res. 27: 207-222.

Cooper, W. E. 1965.
Dynamics and productivity of a natural population of fresh-water emphipod, Hyalella azteca. Ecol. Monog. 35: 377-394.

Cushing, D. H. 1951.
The vertical migration of plankconic crustacea. Biol. Rev. 26: 158-192.

Dendy, J. S. 1946.
Fish distribution, Norris Reservoir, Tennessee, 1943. II. Depth distribution of fish in relation to environmental factors, Norris Reservoir. Rept. Reelfoot Lake Biol. Sta., 9: 114-135.

________. 1948.
Predicting depth distribution of fish in three TVA storage type reservoirs. Trans. Amer. Fish. Soc. for 1945. 75: 65-71.

Dice, L. R. and H. J. Leraas. 1936.
A graphical method for comparing several sets of measurements. Contr. Lab. of Vert. Gen. Univ. of Mich. 3: 1-3.

Dugdale, R. C. 1955.
Studies in the ecology of the benthic Diptera of Lake Mendota. Ph. D. Thesis, Univ. of Wisconsin, Madison.

Edwards, R. W. 1958.
The effect of larvae of _Chironomus_ _riparius_ Meigon on the redox potential of settled activated sludge. Ann. Appl. Biol. 46: 457-464.

Eipper, A. S. 1960.
Managing farm ponds for trout production. New York State Coll. Agri. Cornell Ext. Bull. 1036, Ithaca. 29 pp.

Eschmeyer, W. R. 1938.
Experimental management of a group of small Michigan lakes. Trans. Am. Fish. Soc., 67: 120-129.

Fast, A. W. 1968.
Artificial destratification of El Capitan Reservoir by aeration, part I, effects on chemical and physical parameters. Calif. Dept. Fish and Game, Fish Bull. 141: 97 pp.

Fast, A. W. 1970.
An evaluation of the efficiency of zoobenthos separation by sugar flotation. Prog. Fish. Cult. 32: 212-216.

Fast, A. W. 1971.
Effects of artificial destratification on zooplankton depth distribution. Trans. Amer. Fish Soc. 2: 355-358.

Fast, A. W. and J. St. Amant. (In preparation.)
Nightime artificial aeration of Puddingstone Reservoir, Los Angeles County, California.

Ferguson, R. G. 1958.
The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada, 15: 607-624.

Fitzgerald, G. P. 1970.
Aerobic lake muds for the removal of phosphorus from lake waters. Limnol. Oceanogr. 15: 550-555.

Fry, F. E. J. 1937.
The summer migration of the cisco, *Leuchichtys artedi* (LeSeur), in Lake Nipissing, Ontario. Univ. Toronto Stud., Biol. Ser., 44 (Pub. Ontario Fish. Res. Lab., No. 55), 91 pp.

Galligan, J. P. 1962.
Depth distribution of lake trout and associated species in Cayuga Lake, New York. N. Y. Fish and Game J. 9: 44-68.

Garside, E. T. and J. S. Tait. 1958.
Preferred temperature of rainbow trout (*Salmo gairdneri* Richardson) and its unusual relationship to acclimation temperature. Can. J. Zool. 36: 563-567.

Gleason, G. R. Jr. 1961.
Factors influencing the ecological distribution of *Tendipes decorus* (Joh.) in Coldwater Lake, Isabella County, Michigan. Ph. D. Thesis, Mich. State Univ., E. Lansing, Michigan, 103 pp.

Goldman, C. R. 1962.
Primary productivity and micro-nutrient limiting factors in some North American and New Zealand lakes. Comm. XV Internat. Congr. Limnol.

Hall, D. J. 1964.
An experimental approach to the dynamics of a natural population of *Daphnia galeata mendotae*. Ecol. 45: 94-112.

Harder, G. F. 1968.
Reactions of plankton organisms to water stratification. Limnol and Ocean. 13: 156-168.

Hardy, A. C. 1956.
The open sea. Collins, London. 335 pp.

Hargrave, B. T. 1969.
Similarity of oxygen uptake by benthic communities. Limnol. Oceanogr., 14: 801-805.

Harvey, H. W., L. H. N. Cooper, M. V. Leboor and F. S. Russell. 1935.
Plankton production and its control. J. Mar. Biol. Assoc. U. K. 20: 407-442.

Hasler, A. D. 1963.
Wisconsin 1940-1961. In Limnology in North America. D. G. Frey, ed., The University of Wisconsin Press, Madison, Wisconsin, p. 59.

Hasler, A. D. 1966.
Underwater guideposts, homing of salmon. University of Wisconsin Press, Madison, Wisconsin. 155 pp.

Hilsenhoff, W. L. 1966.
The biology of *Chironomus plumosus* (Diptera: Chironomidae) in Lake Winnebago, Wisconsin. Ann. Entomol. Soc. Amer. 59: 453-73.

Hilsenhoff, W. L. 1967.
Ecology and population dynamics of *Chironomus plumosus* (Diptera: Chironomiade) in Lake Winnebago, Wisconsin. Ann. Entomol. Soc. Amer. 60: 1183-94.

Hilsenhoff, W. L. and R. P. Narf. 1968.
Ecology of Chironomidae, Chaoborinae and other benthos in fourteen Wisconsin lakes. Ann. Entomol. Soc. Amer. 61: 1173-81.

Hodgson, W. C. and I. D. Richardson. 1949.
The experiments on the Cornish Pilchard Fishery in 1947-48. Fish Invest., ser. 2, 17(2).

Hooper, F. F., R. C. Ball and H. A. Tanner. 1952.
An experiment in the artificial circulation of a small Michigan lake. Amer. Fish. Soc., Trans., 82: 222-241.

Horak, D. L. and H. A. Tanner. 1964.
The use of vertical gill nets in studying fish depth distribution, Horsetooth Reservoir, Colorado. Trans. Amer. Fish. Soc. 93: 137-145.

Hrbáček, J., M. Dvořakova, V. Kořínek and L. Procházková. 1961.
Demonstration of the effect of the fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association. Verh. Internat. Verein. Limnol. 14: 192-195.

Hutchinson, G. E. 1941.
Limnological studies in Connecticut. IV. The mechanism of intermediary metabolism in stratified lakes. Ecol. Monogr., 11: 21-60.

Hutchinson, G. E. and V. T. Bowen. 1947.
A direct demonstration of the phosphorus cycle in a small lake. Natl. Acad. Sci. Proc., 33: 148-153.

Hutchinson, G. E. 1957.
A treatise on limnology. Vol. i, Geography, physics and chemistry. John Wiley & Sons, New York. 1015 pp.

Irwin, W. H., J. M. Symons and G. G. Robeck. 1969. Impoundment destratification by mechanical pumping. Proc. Amer. Soc. Civil Engin. 92: 21-40.

Johannes, R. E. and M. Satoni. 1967. Measuring organic matter retained by aquatic invertebrates. J. Fish. Res. Bd. Canada. 24: 2467-2471.

Jónasson, P. M. 1955. The efficiency of sieving techniques for sampling freshwater bottom fauna. Oikos 6: 183-207.

Jónasson, P. M. and J. Kristiansen. 1967. Primary and secondary production in Lake Esrom. Growth of *Chironomus anthracinus* in relation to seasonal cycles of phytoplankton and dissolved oxygen. Int. Revue ges. Hydrobiol. 52: 163-217.

Jones, F. R. H. 1952. The swimbladder and vertical movement of teleostean fish. J. Exptl. Biol. 29: 94-109.

King, D. L. and R. C. Ball. 1964. A quantitative biological measure of stream pullotion. J. Wat. Poll. Control Fed. 36(5): 650-653.

Knoppert, P. L., J. J. Rook, Tj. Hofker and G. Oskam. 1970. Destratification experiments at Rotterdam. J. Amer. Wat. Wks. Assoc. July: 448-454.

Koberg, G. E. 1964. Elimination of thermal stratification in Lake Wohlford, California. U. S. Geol. Surv., Prof. Pap., (501-D): D 190-D 192.

Koberg, G. E., and M. E. Ford. 1965. Elimination of thermal stratification in reservoirs and the resulting benefits. U. S. Geol. Surv., Wat. Supp. Pap., (1809-M): 1-28.

LaRow, E. J. 1968. A persistent diurnal rhythmn in *Chaoborus* larvae. I. The nature of the rhythmicity. Limnol. Oceanogr., 13: 250-256.

Lenz, F. 1925. Chironomiden undseetypenlehre. Die Naturwissenschaften 13: 5-10.

Lindeman, R. L. 1942. The trophic-dynamic aspect of ecology. Ecology 23: 399-418.

Lorenzen, C. J. 1967.
Determination of chlorophyll and pheo-pigments: spectrophotometric equations. Limnol. Oceanogr., 12: 343-346.

Lundbeck, J. 1926.
Die Bodentierweld norddeutscher Seen. Arch. Hydrobiol. Suppl. 7: 1-473.

Lundbeck, J. 1936.
Untersuchungen über die Bodenbesiedelung der Alpenrandseen. Arch. Hydrobiol. 10: 207-258.

McConnell, W. J. 1968.
Limnological effects of organic extracts of litter in a southwestern impoundment. Limnol. Oceanogr. 13: 343-349.

McCarter, J. A., F. R. Hayes, L. H. Jodrey and M. L. Cameron. 1952.
Movement of materials in the hypolimnion of a lake studied by the addition of radioactive phosphorus. Can. J. Zool., 30: 128-133.

McEwen, G. F. 1941.
Observations on temperature, hydrogen-ion concentration and periods of stagnation and overturn in lakes and reservoirs of San Diego, California Scripps. Inst. Ocean., Bull., 4(9): 219-260.

Miller, R. B. 1941.
A contribution to the ecology of the Chironomidae of Costello Lake, Algonquin Park, Ontario. Pub. Ontario Fish. Res. Lab. No. 60, U. of Toronto Press, Toronto, Canada, 63 pp.

Momot, W. T. 1967.
Population dynamics and productivity of the crayfish Orconectes virilis in a marl lake. Amer. Midland Naturalist. 78: 55-81.

Momot, W. T. and H. Gowing. 1970.
Differential seasonal migration of the crayfish Orconectes virilis (Hagen), in small lakes. Michigan Dept. of Natural Resources, Inst. Fish. Res. Rept. 1767: 14 pp. (mimeo.)

Moore, E. W. 1939.
Graphic determination of carbon dioxide and the three forms of alkalinity. J. Amer. Water Wks. Assoc., 31: 51-66.

Mortimer, C. H. 1941.
The exchange of dissolved substances between lake mud and water. J. Ecol. 29: 280-329. 1942. Ibid., 30: 147-201.

Mundie, J. H. 1959.
The diurnal activity of the larger invertebrates at the surface of Lac La Ronge, Saskatchewan. Can. J. Zool. 37: 945-956.

Murphy, G. I. 1962.
Effects of mixing depth and turbidity on the productivity of fresh-water impoundments. J. Amer. Fish. Soc. 91: 69-76.

Northcote, T. G. 1964.
Use of high-frequency echo sounder to record distribution and migration of Chaoborus larvae. Limnol. Oceanogr. 9: 87-91.

Northcote, T. G., H. W. Lorz and J. C. MacLeod. 1964.
Studies on diel vertical movement of fishes in a British Columbia lake. Verh. Internat. Verein. Limnol. 15: 940-946.

Ogborn, C. M. 1966.
Aeration system keeps water tasting fresh. Publ. Wks. (Aug.)

Parsons, T. R. and J. D. H. Strickland. 1963.
Discussion of spectrophotometric determinations of marine plant pigments, with revised equations for ascertaining chlorophills and carotenoids. J. Mar. Res., 21: 155-163.

Pearson, B. E. 1952.
The behavior of a sample of hybrid trout (Salvelinus fontinalis x Cristivomer namaycush) in a vertical temperature gradient. (M. S. Thesis, in Ontario Fish. Res. Lab. Library, Toronto: 24 pp.)

Reisch, D. J. 1959.
A discussion of the importance of screen size in washing quantitative marine bottom samples. Ecol. 40: 307-309.

Rigler, F. H. 1956.
A tracer study of the phosphorus cycle in lakewater. Ecology. 37: 550-562.

Rigler, F. H. 1964.
The contribution of zooplankton to the turnover of phosphorus in the epilimnion of lakes. Canad. Fish Cult., 32: 3-9.

Robinson, E. L., W. H. Irwin and J. M. Symons. 1969.
Influence of artificial destratification on plankton populations in impoundments. Trans. Kentucky Acad. Sci. 30: 1-18.

Roth, J. C. 1968.
Benthic and limnetic distribution of three Chaoborus species in a southern Michigan lake (Diptera, Chaoborinae). Limnol. Oceanogr. 13: 242-249.

Saunders, G. W., F. G. Trama and R. W. Bechmann. 1962.
Evaluation of a modified C-14 technique for shipboard estimation of photosynthesis in large lakes. Great Lakes Research Division, Publ. 8: 61 pp.

Schmidt, P. S. 1915.
Uber den Energiegehalt der Seen. mit beispielen vom Lunzer Untersee nach Messungen miteinem einfacheu Temperaturlot. Int. Rev. Ges. Hydr. Hydrog. Hydrograph., Suppl. 6(1): 1-25.

Scott, I. D. 1921.
Inland lakes of Michigan. Mich. Geol. and Biol. Survey, Publ. 30, Geol. Ser. 25, xxi - 383.

Sharpe, F. F. 1961.
A midsummer plant of rainbow trout in a stratified Tennessee impoundment. Prog. Fish-Cult. 23: 152-155.

Siler, D. H. 1968.
A comparison of invertebrate benthos populations in four sink lakes sixteen years after fertilization. M. S. Thesis, Michigan State University, E. Lansing, Michigan.

Stahl, J. B. 1966.
The ecology of Chaoborus in Myers Lake, Indiana. Limnol. Oceanogr. 11: 177-183.

Strickland, J. D. H. and T. R. Parons. 1965.
A manual of sea water analysis. Fish. Res. Bd. Canada, Bull. 125, end ed., 203 pp.

Sullivan, C. M. and K. D. Fisher. 1953.
Seasonal fluctuations in the selected temperature of speckled trout Salvelinus fontinalis (Mitchill). J. Fish. Res. Bd. Canada. 10: 187-195.

Tanner, H. A. 1952.
Fertilization of Michigan trout lakes. Ph. D. Thesis, Michigan State Univ., E. Lansing, Michigan. 186 pp.

Tanner, H. A. 1960.
Some consequences of adding fertilizer to five Michigan trout lakes. Trans. Amer. Fish. Soc. 89: 198-205.

Teraguchi, M. and T. G. Northcote. 1966.
Vertical distribution and migration of *Chaoborus flavicans* larvae in Corbett Lake, British Columbia. Limnol. Oceanogr. 11: 164-176.

Welch, P. S. 1948.
Limnological methods. McGraw-Hill Book Co., New York. 381 pp.

Wetzel, R. G. 1965.
Necessity for decontamination of filters in C^{14} measured rates of photosynthesis in fresh water. Ecology, 46: 540-542.

Wilkins, L. P. 1952.
Relationships of fish populations to the invertebrate fauna in two small ponds. Thesis, Michigan State College, E. Lansing, Michigan.

Wirth, T. L., R. C. Dunce, P. D. Uttormark and W. Hilsenhoff. 1970.
Manipulation of reservoir waters for improved quality and fish population response. Wisconsin Dept. of Nat. Resources, Madison, Wisc., Res. Rept. 62, 23 pp.

Wynne-Edwards, V. C. 1962.
Animal dispersion in relation to social behavior. Oliver and Boyd, London. 563 pp.

APPENDIX

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Table A-1. Hemlock Lake 17 day periphyton weights during 1969 and 1970. Samples were incubated on plastic slides during June, July and August each year. Four slides were incubated at each of five depths. Ash-free dry weight is shown for each sample.

DEPTHS IN METERS					
0.0	0.9	1.8	2.7	3.7	4.5
Date Collected		7-2-69		Date Set	6-15-69
0.0140	0.0184	0.0177	0.0116	0.0090	0.0059
0.0106	0.0159	0.0144	0.0114	0.0084	0.0043
0.0132	0.0155	0.0161	0.0126	0.0125	0.0068
0.0103	0.0068	0.0172	0.0103	0.0115	0.0091
Date Collected		7-19-69		Date Set	7-2-69
0.0062	0.0118	0.0141	0.0176	0.0027	0.0039
0.0075	0.0186	0.0108	0.0132	0.0035	0.0063
0.0091	0.0122	0.0149	0.0172	0.0100	0.0031
0.0112	0.0133	0.0072	0.0165	0.0091	0.0059
Date Collected		7-28-69		Date Set	7-9-69
0.0122	0.0159	0.0223	0.0176	0.0187	0.0033
0.0145	0.0213	0.0277	0.0451	0.0152	0.0063
0.0146	0.0305	0.0282	0.0470	0.0098	0.0040
0.0305	0.0214	0.0219	0.0167	0.0231	0.0047
Date Collected		8-5-69		Date Set	7-19-69
0.0254	0.0366	0.0341	0.0236	0.0061	0.0095
0.0317	0.0496	0.0440	0.0319	0.0134	0.0172
0.0206	0.0439	0.0342	0.0394	0.0108	0.0159
0.0225	0.0518	[illegible]	0.0437	0.0143	0.0110
Date Collected		8-12-69		Date Set	7-28-69
0.0353	0.0416	0.0337	0.0467	0.0340	0.0495
0.0811	0.0541	0.0289	0.0564	0.0465	0.0140
0.0604	0.0472	0.0345	0.0713	0.0541	0.0217
0.0620	0.0671	0.0327	0.0581	0.0507	0.0263

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Table A-1 (Continued)

DEPTHS IN METERS					
0.0	0.9	1.8	2.7	3.7	4.5
Date Collected 8-22-69				Date Set	8-5-69
0.0374	0.0426	0.0349	0.0378	0.0479	0.0253
0.0267	0.0514	0.0491	0.0414	0.0466	0.0275
0.0337	0.0460	0.0429	0.0462	0.0407	0.0365
0.0416	0.0576	0.0416	0.0528	0.0486	0.0301
Date Collected 8-29-69				Date Set	8-12-69
0.0522	0.0618	0.0461	0.0390	0.0318	0.0226
0.0411	0.0365	0.0428	0.0435	0.0267	0.0198
0.0321	0.0450	0.0491	0.0474	0.0258	0.0198
0.0362	0.0324	0.0375	0.0328	0.0285	0.0245

Table A-1 (Continued)

DEPTHS IN METERS					
0.0	0.9	1.8	2.7	3.7	4.5
Date Collected 7-2-70				Date Set	6-15-70
0.0096	0.0172	0.0091	0.0123	0.0229	0.0033
0.0138	0.0119	0.0164	0.0166	0.0029	0.0015
0.0194	0.0102	0.0118	0.0088	0.0030	0.0016
0.0124	0.0070	0.0094	0.0048	0.0021	0.0040
Date Collected 7-19-70				Date Set	7-2-70
0.0462	0.0503	0.0161	0.0449	0.0393	0.0219
0.0385	0.0306	0.0161	0.0691	0.0426	0.0266
0.0444	0.0347	0.0188	0.0861	0.0367	0.0109
0.0452	0.0337	0.0213	0.0658	0.0467	0.0203
Date Collected 7-26-70				Date Set	7-9-70
0.0366	0.0338	0.0273	0.3219	0.1157	0.1451
0.0374	0.0326	0.0353	0.2668	0.1083	0.0808
0.0387	0.0297	0.0287	0.1658	0.1187	0.1168
0.0422	0.0371	0.0290	0.2223	0.0660	0.0816
Date Collected 8-5-70				Date Set	7-19-70
0.0534	0.0514	0.0740	0.0800	0.0345	0.0241
0.0526	0.0597	0.0583	0.1037	0.0591	0.0240
0.0510	0.0550	0.0575	0.0919	0.0422	0.0286
0.0439	0.0296	0.0498	0.1063	0.0363	0.0221
Date Collected 8-12-70				Date Set	7-26-70
0.0581	0.0564	0.0513	0.0604	0.0333	0.0192
0.0639	0.0579	0.0560	0.0654	0.0323	0.0290
0.0520	0.0619	0.0608	0.0727	0.0367	0.0270
0.0578	0.0572	0.0622	0.0639	0.0404	0.0138

Table A-1 (Continued)

DEPTHS IN METERS					
0.0	0.9	1.8	2.7	3.7	4.5
Date Collected	8-21-70			Date Set	8-5-70
0.0669	0.0645	0.0626	0.0902	0.0612	0.0482
0.0636	0.0664	0.0645	0.0789	0.0578	0.0358
0.0714	0.0648	0.0698	0.0851	0.0642	0.0398
0.0748	0.0650	0.0662	0.0745	0.0592	0.0463
Date Collected	8-29-70			Date Set	8-12-70
0.0492	0.0648	0.0718	0.0429	0.0814	0.1153
0.0559	0.0676	0.0669	0.0493	0.0893	0.1256
0.0643	0.0653	0.0669	0.0595	0.0883	0.1282
0.0431	0.0520	0.0878	0.0455	0.0926	0.0897

Table A-2. Hemlock Lake accumulative periphyton weights during 1969 and 1970. Samples were incubated starting June 15 each year and a portion was retrieved at different times during the summer. Samples were incubated on plastic slides. These slides were incubated at each of five depths. Ash-free dry weight is shown for each sample.

DEPTHS IN METERS

0.0	0.9	1.8	2.7	3.7	4.5
Date Collected	7-19-69			Date Set	6-15-69
0.0142	0.0474	0.0518	0.0216	0.0224	0.0136
0.0549	0.0383	0.0463	0.0198	0.0179	0.0069
0.0278	0.0322	0.0338	0.0201	0.0104	0.0122
Date Collected	8-5-69			Date Set	6-15-69
0.0859	0.1486	0.1652	0.0953	0.0685	0.0282
0.0494	0.1127	0.1179	0.0712	0.0340	0.0282
0.0354	0.0809	0.0899	0.0822	0.0245	0.0423
Date Collected	8-22-69			Date Set	6-15-69
0.1773	0.1855	0.1902	0.1266	0.0790	0.0722
0.0841	0.1427	0.1217	0.2471	0.0898	0.0506
0.0982	0.2042	0.1257	0.1032	0.0748	0.0849

Table A-2 (Continued)

DEPTHS IN METERS 0.0	0.9	1.8	2.7	3.7	4.5
Date Collected	7-19-70			Date Set	6-15-70
0.0861	0.0746	0.0753	0.0497	0.0338	0.0217
0.0933	0.0785	0.0410	0.1180	0.0527	0.0480
0.0619	0.0626	0.0890	0.1491	0.1237	0.0424
Date Collected	8-5-70			Date Set	6-15-70
0.0631	0.1425	0.1187	0.1371	0.0532	0.0393
0.0706	0.1338	0.1072	0.1464	0.0690	0.0473
0.0571	0.1460	0.1511	0.1301	0.0874	0.0337
Date Collected	8-21-70			Date Set	6-15-70
0.2449	0.2712	0.2796	0.2468	0.1200	0.0949
0.2262	0.2598	0.2360	0.2351	0.1110	0.0851
0.2066	0.2806	0.2515	0.1801	0.1202	0.1043

Table A-3. Section Four Lake 17 day periphyton weights during 1969 and 1970. Samples were incubated on plastic slides during June, July and August each year. Four slides were incubated at each of five depths. Ash-free dry weight is shown for each sample.

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected	7-2-69			Date Set	6-15-69
0.0110	0.0133	0.0220	0.0118	0.0074	0.0092
0.0120	0.0139	0.0173	0.0141	0.0058	0.0072
0.0118	0.0137	0.0199	0.0075	0.0103	0.0049
0.0155	0.0129	0.0135	0.0075	0.0083	0.0072
Date Collected	7-19-69			Date Set	7-2-69
0.0129	0.0061	0.0235	0.0103	0.0186	0.0111
0.0108	0.0123	0.0129	0.0177	0.0190	0.0114
0.0107	0.0112	0.0107	0.0202	0.0177	0.0127
0.0226	0.0145	0.0083	0.0210	0.0196	0.0180
Date Collected	7-28-69			Date Set	7-9-69
0.0066	0.0105	0.0090	0.0079	0.0068	0.0104
0.0114	0.0109	0.0114	0.0118	0.0084	0.0081
0.0078	0.0105	0.0137	0.0150	0.0039	0.0016
0.0095	0.0084	0.0168	0.0103	0.0087	0.0038
Date Collected	8-6-69			Date Set	7-19-69
0.0060	0.0103	0.0118	0.0077	0.0084	0.0080
0.0070	0.0117	0.0122	0.0101	0.0137	0.0086
0.0074	0.0127	0.0069	0.0144	0.0057	0.0092
0.0161	0.0101	0.0079	0.0098	0.0087	0.0107
Date Collected	8-12-69			Date Set	7-28-69
0.0071	0.0065	0.0102	0.0235	0.0063	0.0027
0.0070	0.0147	0.0125	0.0142	0.0017	0.0045
0.0066	0.0095	0.0089	0.0115	0.0052	0.0061
0.0119	0.0275	0.0099	0.0191	0.0157	0.0197

Table A-3 (Continued)

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected	8-22-69			Date Set	8-6-69
0.0020	0.0057	0.0217	0.0184	0.0099	0.0084
0.0145	0.0180	0.0175	0.0108	0.1176	0.0102
0.0030	0.0158	0.0094	0.0047	0.0071	0.0088
0.0064	0.0112	0.0179	0.0146	0.0125	0.0088
Date Collected	8-29-69			Date Set	8-12-69
0.0100	0.0070	0.0162	0.0145	0.0157	0.0114
0.0059	0.0109	0.0147	0.0167	0.0120	0.0084
0.0146	0.0034	0.0194	0.0127	0.0198	0.0046
0.0207	0.0042	0.0160	0.0141	0.0093	0.0071

Table A-3 (Continued)

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected	7-2-70			Date Set	6-15-70
0.0031	0.0056	0.0025	0.0075	0.0078	0.0070
0.0017	0.0091	0.0061	0.0083	0.0094	0.0044
0.0046	0.0066	0.0063	0.0077	0.0124	0.0041
0.0018	0.0049	0.0084	0.0078	0.0185	0.0054
Date Collected	7-19-70			Date Set	7-2-70
0.0068	0.0149	0.0172	0.0198	0.0268	0.0133
0.0076	0.0196	0.0252	0.0242	0.0178	0.0178
0.0062	0.0201	0.0305	0.0166	0.0201	0.0168
0.0069	0.0165	0.0207	0.0290	0.1231	0.0110
Date Collected	7-26-70			Date Set	7-9-70
0.0141	0.0305	0.0980	0.0244	0.0195	0.0259
0.0103	0.0285	0.0334	0.0307	0.0291	0.0233
0.0120	0.0254	0.0415	0.0276	0.0187	0.0247
0.0150	0.0667	0.0378	0.0256	0.0281	0.0123
Date Collected	8-5-70			Date Set	7-19-70
0.0121	0.0230	0.0195	0.0210	0.0243	0.0114
0.0182	0.0223	0.0219	0.0177	0.0193	0.0126
0.0179	0.0258	0.0280	0.0269	0.0159	0.0110
0.0154	0.0242	0.0191	0.0138	0.0169	0.0136
Date Collected	8-12-70			Date Set	7-26-70
0.0114	0.0300	0.0344	0.0203	0.0189	0.0155
0.0118	0.0339	0.0111	0.0399	0.0246	0.0156
0.0155	0.0192	0.0194	0.0279	0.0210	0.0162
0.0189	0.0339	0.0130	0.0181	0.0210	0.0167

Table A-3 (Continued)

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected	8-21-70			Date Set	8-5-70
0.0192	0.0270	0.0246	0.0272	0.0178	0.0110
0.0196	0.0310	0.0241	0.0251	0.0208	0.0101
0.0177	0.0246	0.0262	0.0210	0.0180	0.0144
0.0268	0.0272	0.0269	0.0221	0.0183	0.0084
Date Collected	8-29-70			Date Set	8-12-70
0.0148	0.0287	0.0288	0.0352	0.0268	0.0141
0.0153	0.0359	0.0229	0.0356	0.0277	0.0166
0.0182	0.0381	0.0336	0.0369	0.0346	0.0140
0.0145	0.0378	0.0253	0.0189	0.0286	0.0199

Table A-4. Section Four Lake accumulative periphyton weights during 1969 and 1970. Samples were incubated starting June 15 each year and a portion was retrieved at different times during the summer. Samples were incubated on plastic slides. These slides were incubated at each of five depths. Ash-free dry weight is shown for each sample.

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected		7-19-69		Date Set	6-15-69
0.0393	0.0252	0.0166	0.0184	0.0204	0.0120
0.0152	0.0185	0.0253	0.0228	0.0141	0.0178
0.0107	0.0228	0.0184	0.0111	0.0185	0.0139
Date Collected		8-6-69		Date Set	6-15-69
0.0318	0.0482	0.0472	0.0327	0.0247	0.0237
0.0356	0.0536	0.0735	0.0282	0.0335	0.0264
0.0304	0.0606	0.0390	0.0357	0.0657	0.0283
Date Collected		8-22-69		Date Set	6-15-69
0.1534	0.0757	0.1010	0.0575	0.0515	0.0311
0.0299	0.1373	0.2195	0.2635	0.0335	0.0304
0.2914	0.1517	0.0623	0.0511	0.0304	0.0303

Table A-4 (Continued)

DEPTHS IN METERS					
0.0	1.8	3.7	5.4	7.3	9.3
Date Collected	7-19-70			Date Set	6-15-70
0.0142	0.0323	0.0355	0.0383	0.0278	0.0583
0.0107	0.0366	0.0453	0.0429	0.0301	0.0433
0.0092	0.0309	0.0332	0.0425	0.0015	0.0281
Date Collected	8-5-70			Date Set	6-15-70
0.0291	0.0630	0.0648	0.0575	0.0277	0.0195
0.0325	0.0652	0.0427	0.0564	0.0425	0.0211
0.0293	0.0633	0.0701	0.0577	0.0350	0.0404
Date Collected	8-21-70			Date Set	6-15-70
0.0490	0.1083	0.1236	0.1000	0.0969	0.0405
0.0536	0.1214	0.1030	0.0653	0.0748	0.0340
0.0535	0.0890	0.1355	0.1278	0.0772	0.0558

Table A-5. Hemlock Lake zoobenthos collected with an Ekman dredge during 1969 and 1970. Numbers and wet weights for the seven most abundant taxa are shown in this table for each sample. 125 samples were collected each summer. The less abundant taxa are listed in Table A-6. To verify the total organisms for a given sample, consult both tables. Depth is in meters and weight is in grams.

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Mayflies No.	Mayflies Wt.	Chaoborus L. No.	Chaoborus L. Wt.	Chaoborus P. No.	Chaoborus P. Wt.	Heleidae No.	Heleidae Wt.
6-13-69															
1	15.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	6	0.002339	2	0.013074	0	0.000000
2	16.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.002742	1	0.001037	0	0.000000
3	15.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	7	0.002443	0	0.000000	0	0.000000
4	15.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	9	0.007949	1	0.000945	0	0.000000
5	15.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	8	0.009722	0	0.000000	0	0.000000
6	14.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.000418	0	0.000000	0	0.000000
7	14.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	14	0.010680	1	0.000874	0	0.000000
8	13.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	11	0.007672	1	0.001240	0	0.000000
9	12.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	18	0.011638	0	0.000000	0	0.000000
10	12.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	29	0.017525	2	0.002777	0	0.000000
11	10.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	40	0.024427	10	0.009640	0	0.000000
12	9.6	0	0.000000	2	0.001062	0	0.000000	0	0.000000	2	0.002856	0	0.000000	0	0.000000
13	7.5	0	0.000000	23	0.004367	0	0.000000	0	0.000000	20	0.015112	6	0.010270	1	0.001182
14	9.2	0	0.000000	14	0.003997	0	0.000000	0	0.000000	10	0.007879	3	0.005007	0	0.000000
15	8.3	0	0.000000	32	0.009144	0	0.000000	0	0.000000	4	0.003325	2	0.002676	1	0.000912
16	6.9	0	0.000000	14	0.007068	0	0.000000	0	0.000000	10	0.006468	2	0.003642	2	0.000342
17	6.2	0	0.000000	41	0.040451	0	0.000000	0	0.000000	14	0.006407	4	0.012160	0	0.000000
18	4.6	0	0.000000	22	0.008452	0	0.000000	0	0.000000	18	0.011059	11	0.013505	2	0.002971
19	6.4	0	0.000000	5	0.001444	0	0.000000	0	0.000000	1	0.000316	1	0.000976	1	0.000653
20	4.6	0	0.000000	19	0.008793	0	0.000000	0	0.000000	8	0.005127	3	0.002355	2	0.002524
21	3.0	0	0.000000	14	0.003842	0	0.000000	2	0.000798	0	0.000000	1	0.000730	0	0.000000
22	2.3	0	0.000000	14	0.004136	1	0.000194	0	0.000000	0	0.000000	0	0.000000	0	0.000000
23	1.6	0	0.000000	9	0.005714	0	0.000000	1	0.000560	0	0.000000	0	0.000000	[illegible]	0.000000
24	1.0	0	0.000000	17	0.002697	0	0.000000	4	0.001520	0	0.000000	0	0.000000	0	0.000000
25	0.3	0	0.000000	51	0.004725	1	0.000088	1	0.000629	0	0.000000	0	0.000000	0	0.000000
7-4-69															
101	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	11	0.007579	2	0.002270	0	0.000000
102	16.9	0	0.000000	0	0.000000	0	0.000000	0	0.000000	11	0.009043	2	0.002203	0	0.000000
103	16.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	9	0.008026	0	0.000000	0	0.000000
104	15.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	11	0.008793	1	0.000653	0	0.000000
105	15.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.003142	0	0.000000	0	0.000000
106	14.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.001055	0	0.000000	0	0.000000
107	13.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	15	0.010921	0	0.000000	0	0.000000
108	12.3	0	0.000000	1	0.000164	0	0.000000	0	0.000000	16	0.012084	0	0.000000	0	0.000000
109	13.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.002552	0	0.000000	0	0.000000
110	11.4	0	0.000000	1	0.000495	0	0.000000	0	0.000000	8	0.006492	0	0.000000	0	0.000000
111	10.7	0	0.000000	4	0.001055	0	0.000000	1	0.000348	15	0.013125	0	0.000000	0	0.000000
112	10.1	0	0.000000	1	0.000160	0	0.000000	0	0.000000	5	0.004211	1	0.001246	0	0.000000
113	8.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	9	0.009479	1	0.000969	0	0.000000
114	9.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	12	0.011695	1	0.001175	0	0.000000
115	7.8	1	0.000807	0	0.000000	0	0.000000	0	0.000000	5	0.003100	0	0.000000	2	0.000558
116	7.1	1	0.001200	8	0.004809	0	0.000000	0	0.000000	13	0.009874	1	0.000845	1	0.000214
117	6.0	0	0.000000	1	0.000563	0	0.000000	0	0.000000	5	0.003972	0	0.000000	2	0.000608
118	5.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	4	0.002097	0	0.000000	10	0.003064
119	5.0	0	0.000000	74	0.020104	2	0.000294	0	0.000000	1	0.000613	1	0.000709	0	0.000000

Table A-5 (Continued)

Sample Number	Depth	Oligochaeta No.	Wt.	Chironomid L. No.	Wt.	Chironomid P. No.	Wt.	Mayflies No.	Wt.	Chaoborus L. No.	Wt.	Chaoborus P. No.	Wt.	Heleidae No.	Wt.
120	4.3	0	0.000000	12	0.004593	0	0.000000	0	0.000000	1	0.000365	1	0.000570	0	0.000000
121	3.7	0	0.000000	20	0.004957	1	0.000283	0	0.000000	0	0.000000	0	0.000000	0	0.000000
122	2.3	0	0.000000	2	0.000626	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
123	2.9	0	0.000000	30	0.005807	1	0.000123	1	0.000791	0	0.000000	0	0.000000	0	0.000000
124	1.4	0	0.000000	80	0.010618	1	0.000060	4	0.002167	0	0.000000	0	0.000000	0	0.000000
125	0.7	0	0.000000	90	0.008071	1	0.000190	19	0.013419	0	0.000000	0	0.000000	0	0.000000
7-25-69															
201	17.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
202	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
203	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
204	16.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
205	15.3	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
206	14.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
207	13.7	0	0.000000	0	0.000000	0	0.006000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
208	13.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
209	12.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
210	12.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
211	10.5	0	0.000000	2	0.000574	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
212	8.7	0	0.000000	2	0.000768	0	0.000000	0	0.000000	1	0.000767	0	0.000000	0	0.000000
213	9.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.002268	0	0.000000	0	0.000000
214	7.8	0	0.000000	1	0.000030	0	0.000000	0	0.000000	1	0.000436	0	0.000000	0	0.000000
215	8.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
216	7.3	0	0.000000	4	0.003788	0	0.000000	0	0.000000	1	0.000762	1	0.000885	0	0.000000
217	6.9	0	0.000000	5	0.001082	0	0.000000	0	0.000000	2	0.000754	0	0.000000	1	0.000117
218	6.0	0	0.000000	13	0.002360	1	0.000073	0	0.000000	0	0.000000	0	0.000000	0	0.000000
219	5.0	0	0.000000	7	0.002029	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.002063
220	4.6	0	0.000000	17	0.005782	1	0.000066	0	0.000000	0	0.000000	0	0.000000	0	0.000000
221	3.2	0	0.000000	4	0.000218	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
222	2.7	0	0.000000	23	0.001429	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
223	1.8	0	0.000000	6	0.000253	0	0.000000	1	0.000051	0	0.000000	0	0.000000	1	0.000039
224	1.4	0	0.000000	39	0.002314	3	0.000267	1	0.002655	0	0.000000	0	0.000000	1	0.000120
225	0.7	0	0.000000	30	0.003501	4	0.000276	43	0.017489	0	0.000000	0	0.000000	0	0.000000
8-15-69															
301	17.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	4	0.003367	1	0.001791	0	0.000000
302	16.9	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000769	0	0.000000	0	0.000000
303	16.9	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.001700	0	0.000000	0	0.000000
304	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.001494	0	0.000000	0	0.000000
305	16.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.003742	0	0.000000	0	0.000000
306	14.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.000940	5	0.006079	0	0.000000
307	13.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	9	0.009658	2	0.002257	0	0.000000
308	13.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	6	0.006078	0	0.000000	0	0.000000
309	12.6	0	0.000000	4	0.001162	0	0.000000	0	0.000000	7	0.007245	1	0.001325	0	0.000000
310	12.0	0	0.000000	5	0.001361	0	0.000000	0	0.000000	4	0.003729	1	0.001514	0	0.000000
311	10.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	13	0.015894	3	0.004065	0	0.000000
312	9.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	6	0.005475	0	0.000000	0	0.000000

Table A-5 (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Mayflies No.	Mayflies Wt.	Chaoborus L. No.	Chaoborus L. Wt.	Chaoborus P. No.	Chaoborus P. Wt.	Heleidae No.	Heleidae Wt.
313	8.7	0	0.000000	2	0.001487	0	0.000000	0	0.000000	3	0.002953	3	0.003871	0	0.000000
314	8.3	0	0.000000	28	0.018956	0	0.000000	0	0.000000	1	0.000479	3	0.004301	2	0.000442
315	7.3	1	0.000442	30	0.012203	1	0.000192	0	0.000000	1	0.000594	1	0.002051	0	0.000000
316	7.3	0	0.000000	5	0.001011	0	0.000000	0	0.000000	4	0.001634	1	0.002074	31	0.018306
317	6.9	0	0.000000	4	0.000812	0	0.000000	0	0.000000	6	0.003496	2	0.002404	0	0.000000
318	6.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
319	5.0	0	0.000000	21	0.008194	2	0.004295	0	0.000000	1	0.000746	0	0.000000	6	0.005091
320	4.8	0	0.000000	26	0.007209	3	0.001834	0	0.000000	0	0.000000	0	0.000000	7	0.007542
321	3.2	0	0.000000	11	0.002274	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000165
322	2.5	0	0.000000	14	0.001255	0	0.000000	1	0.000103	0	0.000000	0	0.000000	0	0.000000
323	1.8	0	0.000000	4	0.000538	0	0.000000	2	0.000505	0	0.000000	0	0.000000	0	0.000000
324	0.9	0	0.000000	63	0.005374	0	0.000000	9	0.001182	0	0.000000	0	0.000000	1	0.000082
325	0.5	0	0.000000	64	0.006092	2	0.000182	3	0.001010	0	0.000000	0	0.000000	0	0.000000
9-6-69															
401	17.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.000923	0	0.000000	0	0.000000
402	17.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.002929	0	0.000000	0	0.000000
403	17.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.001823	2	0.001660	0	0.000000
404	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.000718	0	0.000000	0	0.000000
405	15.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000844	0	0.000000	0	0.000000
406	14.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.001230	1	0.003538	0	0.000000
407	12.8	0	0.000000	2	0.000574	0	0.000000	0	0.000000	3	0.002643	0	0.000000	0	0.000000
408	13.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	4	0.002263	0	0.000000	0	0.000000
409	12.0	0	0.000000	8	0.006546	0	0.000000	0	0.000000	1	0.000903	0	0.000000	0	0.000000
410	11.4	0	0.000000	7	0.001930	0	0.000000	0	0.000000	6	0.006074	0	0.000000	0	0.000000
411	10.5	0	0.000000	3	0.000613	0	0.000000	0	0.000000	20	0.013576	0	0.000000	0	0.000000
412	7.8	0	0.000000	17	0.011584	0	0.000000	0	0.000000	2	0.000752	0	0.000000	0	0.000000
413	8.7	0	0.000000	5	0.003208	0	0.000000	0	0.000000	2	0.001923	0	0.000000	1	0.000316
414	9.4	0	0.000000	8	0.006087	0	0.000000	0	0.000000	14	0.007097	1	0.001228	0	0.000000
415	8.7	0	0.000000	6	0.002373	0	0.000000	0	0.000000	1	0.000687	1	0.001728	0	0.000000
416	6.9	1	0.001023	48	0.004146	1	0.001935	0	0.000000	0	0.000000	0	0.000000	2	0.000608
417	7.3	0	0.000000	34	0.005071	0	0.000000	0	0.000000	0	0.000000	0	0.000000	5	0.001536
418	5.0	0	0.000000	18	0.002413	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
419	6.[illegible]	0	0.000000	1	0.000147	0	0.000000	0	0.000000	0	0.000000	0	0.000000	7	0.005464
420	4.3	0	0.000000	20	0.001984	3	0.010601	1	0.000176	0	0.000000	0	0.000000	0	0.000000
421	3.4	0	0.000000	15	0.001502	0	0.000000	4	0.000405	0	0.000000	0	0.000000	0	0.000000
422	2.1	0	0.000000	16	0.001885	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000228
423	1.8	0	0.000000	9	0.000913	1	0.000110	0	0.000000	0	0.000000	0	0.000000	0	0.000000
424	0.9	0	0.000000	152	0.008952	2	0.018306	17	0.001671	0	0.000000	0	0.000000	0	0.000000
425	0.5	0	0.000000	29	0.002256	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
6-12-70															
1001	0.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1002	0.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1003	17.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.001574	0	0.000000	0	0.000000
1004	16.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.001630	0	0.000000	0	0.000000
1005	16.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.001161	0	0.000000	0	0.000000

Table A-5 (continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Mayflies No.	Mayflies Wt.	Chaoborus L. No.	Chaoborus L. Wt.	Chaoborus P. No.	Chaoborus P. Wt.	Heleidae No.	Heleidae Wt.
1006	0.0	0	0.000000	0	0.000000	0	0.000000	[illegible]	0.000030	0	0.000000	0	0.000000	0	0.000000
1007	13.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	[illegible]	0.000535	0	0.000000	0	0.000000
1008	0.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1009	0.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1010	12.0	0	0.000000	4	0.000157	0	0.000000	0	0.000000	2	0.002212	0	0.000000	0	0.000000
1011	11.0	0	0.000000	4	0.001170	0	0.000000	0	0.000000	1	0.002586	1	0.000852	0	0.000000
1012	10.5	0	0.000000	6	0.005486	0	0.000000	0	0.000000	4	0.002576	0	0.000000	0	0.000000
1013	10.1	0	0.000000	11	0.006766	0	0.000000	0	0.000000	7	0.006233	1	0.001118	1	0.000222
1014	8.7	0	0.000000	3	0.001525	0	0.000000	0	0.000000	8	0.006715	0	0.000000	1	0.000062
1015	7.8	0	0.000000	6	0.003202	0	0.000000	1	0.000050	3	0.002793	1	0.000774	0	0.000000
1016	7.3	0	0.000000	22	0.011157	0	0.000000	0	0.000000	3	0.001824	2	0.001939	9	0.001004
1017	6.9	0	0.000000	3	0.001426	0	0.000000	0	0.000000	13	0.001685	1	0.000928	0	0.000000
1018	5.3	0	0.000000	48	0.028546	0	0.000000	1	0.000066	0	0.000000	2	0.001822	2	0.000388
1019	4.6	0	0.000000	52	0.016277	0	0.000000	1	0.000275	0	0.000000	0	0.000000	0	0.000000
1020	3.9	0	0.000000	24	0.003680	1	0.001078	3	0.000075	0	0.000000	0	0.000000	1	0.000037
1021	3.2	0	0.000000	15	0.002233	0	0.000000	1	0.000257	0	0.000000	0	0.000000	2	0.003432
1022	1.8	0	0.000000	12	0.002606	0	0.000000	19	0.005706	0	0.000000	0	0.000000	1	0.000215
1023	1.4	0	0.000000	9	0.001168	0	0.000000	5	0.000942	0	0.000000	0	0.000000	0	0.000000
1024	0.5	0	0.000000	10	0.000553	0	0.000000	6	0.001575	6	0.004714	1	0.000559	0	0.000000
1025	0.3	0	0.000000	5	0.000328	0	0.000000	11	0.001661	0	0.000000	0	0.000000	0	0.000000
7-3-70															
2001	17.8	0	0.000000	1	0.000193	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2002	17.4	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000986	0	0.000000	0	0.000000
2003	16.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.002013	0	0.000000	0	0.000000
2004	16.0	0	0.000000	0	0.000000	0	0.000000	0	0.000000	3	0.000163	0	0.000000	0	0.000000
2005	15.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	5	0.000234	0	0.000000	0	0.000000
2006	14.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2007	13.7	0	0.000000	1	0.000606	0	0.000000	0	0.000000	1	0.000045	0	0.000000	0	0.000000
2008	13.5	0	0.000000	0	0.000000	0	0.000000	0	0.000000	1	0.000132	0	0.000000	0	0.000000
2009	12.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	4	0.001263	0	0.000000	0	0.000000
2010	12.0	0	0.000000	1	0.000564	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2011	11.0	4	0.001083	7	0.004382	0	0.000000	0	0.000000	1	0.000136	1	0.000810	0	0.000000
2012	10.3	88	0.018548	28	0.012183	0	0.000000	0	0.000000	1	0.000524	0	0.000000	4	0.000341
2013	9.6	7	0.001453	1	0.000214	0	0.000000	0	0.000000	8	0.004832	0	0.000000	0	0.000000
2014	8.0	2	0.000124	11	0.010630	1	0.001110	0	0.000000	4	0.001427	0	0.000000	4	0.001010
2015	8.5	0	0.000000	2	0.000990	0	0.000000	0	0.000000	3	0.000113	0	0.000000	0	0.000000
2016	7.1	0	0.000000	12	0.008927	0	0.000000	0	0.000000	5	0.000788	4	0.003438	0	0.000000
2017	6.9	4	0.004159	13	0.007622	0	0.000000	0	0.000000	3	0.000341	1	0.000819	0	0.000000
2018	4.6	2	0.003062	36	0.030185	1	0.001110	0	0.000000	6	0.001083	6	0.004837	1	0.000267
2019	5.0	0	0.000000	20	0.017539	0	0.000000	0	0.000000	8	0.000787	1	0.000701	1	0.000359
2020	4.3	0	0.000000	42	0.008507	0	0.000000	0	0.000000	6	0.001461	8	0.005260	2	0.000617
2021	3.2	2	0.000259	10	0.003254	0	0.000000	2	0.000666	0	0.000000	1	0.000388	0	0.000000
2022	2.5	0	0.000000	9	0.000720	0	0.000000	2	0.000551	0	0.000000	0	0.000000	0	0.000000
2023	1.6	0	0.000000	53	0.002923	0	0.000000	6	0.002070	0	0.000000	0	0.000000	0	0.000000
2024	0.9	0	0.000000	131	0.006770	3	0.000150	7	0.002788	0	0.000000	0	0.000000	0	0.000000
2025	0.3	1	0.000160	260	0.012253	5	0.000378	13	0.003021	0	0.000000	0	0.000000	0	0.000000

Table [illegible] (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Mayflies No.	Mayflies Wt.	Chaoborus L. No.	Chaoborus L. Wt.	Chaoborus P. No.	Chaoborus P. Wt.	Heleidae No.	Heleidae Wt.
7-24-70															
3001	18.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	18	0.002534	1	0.000960	0	0.000000
3002	17.6	0	0.000000	1	0.000113	0	0.000000	0	0.000000	[illegible]	0.002945	0	0.000000	0	0.000000
3003	16.7	0	0.000000	6	0.000000	0	0.000000	0	0.000000	[illegible]	0.007430	1	0.000614	0	0.000000
3004	16.7	0	0.000000	0	0.000000	0	0.000000	0	0.000000	21	0.002454	0	0.000000	0	0.000000
3005	16.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	45	0.006981	0	0.000000	0	0.000000
3006	14.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	74	0.002142	0	0.000000	0	0.000000
3007	14.2	0	0.000000	0	0.000000	0	0.000000	0	0.000000	34	0.007453	0	0.000000	0	0.000000
3008	12.3	6	0.001384	4	0.000885	1	0.000107	0	0.000000	33	0.007448	0	0.000000	0	0.000000
3009	11.4	2	0.000337	6	0.005038	0	0.000000	0	0.000000	25	0.004476	1	0.000513	0	0.000000
3010	12.6	0	0.000000	0	0.000000	0	0.000000	0	0.000000	21	0.004675	1	0.000645	0	0.000000
3011	11.0	2	0.000457	10	0.004102	2	0.000306	0	0.000000	100	0.016080	2	0.001046	0	0.000000
3012	10.5	1	0.001051	11	0.005610	0	0.000000	0	0.000000	48	0.008715	0	0.000000	0	0.000000
3013	9.6	7	0.004039	0	0.000000	0	0.000000	0	0.000000	16	0.004008	1	0.001062	0	0.000000
3014	7.8	0	0.000000	2	0.000031	0	0.000000	0	0.000000	68	0.011200	0	0.000000	0	0.000000
3015	8.5	0	0.000000	10	0.004292	0	0.000000	0	0.000000	48	0.010063	1	0.000515	0	0.000000
3016	7.3	1	0.000117	45	0.011427	2	0.000347	0	0.000000	33	0.007372	0	0.000000	2	0.000269
3017	6.7	2	0.002728	31	0.014501	0	0.000000	0	0.000000	31	0.010005	1	0.000607	7	0.000406
3018	5.0	1	0.000240	1	0.001617	0	0.000000	0	0.000000	25	0.005735	2	0.001276	2	0.000586
3019	5.5	0	0.000000	15	0.001494	0	0.000000	0	0.000000	66	0.018560	4	0.002521	0	0.000000
3020	4.1	0	0.000000	45	0.004718	4	0.000860	0	0.000000	4	0.000440	2	0.001772	3	0.001106
3021	3.4	1	0.000074	172	0.018816	3	0.000296	1	0.000074	6	0.001905	1	0.000736	0	0.000000
3022	1.8	0	0.000000	17	0.000701	0	0.000000	0	0.000000	1	0.000530	0	0.000000	0	0.000000
3023	2.5	0	0.000000	73	0.008740	10	0.001464	2	0.000563	0	0.000000	0	0.000000	0	0.000000
3024	0.9	0	0.000000	78	0.007050	4	0.000855	2	0.000312	0	0.000000	0	0.000000	1	0.000161
3025	0.3	0	0.000000	147	0.012557	7	0.000508	7	0.001542	0	0.000000	0	0.000000	1	0.000113
8-14-70															
4001	18.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	26	0.003743	2	0.001387	0	0.000000
4002	17.4	0	0.000000	1	0.000159	0	0.000000	0	0.000000	15	0.004067	1	0.000159	0	0.000000
4003	16.9	0	0.000000	0	0.000000	0	0.000000	0	0.000000	51	0.005508	1	0.000453	0	0.000000
4004	16.1	0	0.000000	0	0.000000	0	0.000000	0	0.000000	45	0.010303	0	0.000000	0	0.000000
4005	15.1	0	0.000000	5	0.000903	1	0.002072	0	0.000000	11	0.002567	1	0.000119	0	0.000000
4006	14.6	0	0.000000	1	0.000404	0	0.000000	0	0.000000	35	0.007870	[illegible]	0.002344	0	0.000000
4007	13.7	0	0.000000	1	0.000192	0	0.000000	0	0.000000	26	0.005705	0	0.000000	0	0.000000
4008	12.6	11	0.002000	23	0.023224	1	0.000330	0	0.000000	15	0.002281	0	0.000000	0	0.000000
4009	11.7	0	0.000000	[illegible]	0.004328	1	0.000800	0	0.000000	7	0.002226	2	0.001099	0	0.000000
4010	12.0	7	0.002178	8	0.010667	3	0.006105	0	0.000000	6	0.002014	0	0.000000	0	0.000000
4011	11.0	5	0.003687	3	0.000587	0	0.000000	0	0.000000	21	0.004824	2	0.001167	0	0.000000
4012	9.6	2	[illegible]	27	0.010015	5	0.001004	1	0.000162	8	0.001388	3	0.001304	0	0.000000
4013	8.7	4	[illegible]	4	[illegible]	0	0.000000	0	0.000000	13	0.002659	5	0.001169	0	0.000000
4014	10.1	1	0.000141	18	0.005115	2	0.000073	0	0.000000	16	0.005156	0	0.000000	2	0.000322
4015	[illegible]	0	0.000000	17	0.013001	0	0.000000	0	0.000000	11	0.002385	2	0.001001	0	0.000000
4016	7.3	1	[illegible]	21	[illegible]	2	[illegible]	0	0.000000	6	[illegible]	0	0.000000	0	0.000000
4017	6.0	0	0.000000	[illegible]	[illegible]	[illegible]	0.000000	0	0.000000	22	0.001907	1	0.001381	4	0.000832
4018	5.5	0	0.000000	31	0.006210	3	[illegible]	0	0.000000	3	[illegible]	1	0.000580	0	0.000000
4019	4.6	0	0.000000	[illegible]	[illegible]	1	0.000150	0	0.000000	2	[illegible]	0	0.000000	1	0.000615

Table A-5 (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Mayflies No.	Mayflies Wt.	Chaoborus L. No.	Chaoborus L. Wt.	Chaoborus P. No.	Chaoborus P. Wt.	Heleidae No.	Heleidae Wt.
4020	3.9	0	0.000000	136	0.011041	8	0.000747	0	0.000000	4	0.000321	0	0.000000	4	0.002745
4021	3.0	0	0.000000	6	0.000450	1	0.000086	0	0.000000	0	0.000000	0	0.000000	0	0.000000
4022	2.1	0	0.000000	18	0.000760	2	0.000176	2	0.000151	0	0.000000	0	0.000000	0	0.000000
4023	1.6	0	0.000000	8	0.000886	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
4024	1.2	0	0.000000	42	0.002043	0	0.000000	1	0.000150	0	0.000000	0	0.000000	0	0.000000
4025	0.3	0	0.000000	59	0.002828	1	0.000119	9	0.000683	0	0.000000	0	0.000000	1	0.000025
9-4-70															
5001	18.3	0	0.000000	2	0.003847	0	0.000000	0	0.000000	10	0.001336	0	0.000000	0	0.000000
5002	17.8	0	0.000000	0	0.000000	0	0.000000	0	0.000000	25	0.005454	0	0.000000	0	0.000000
5003	16.9	0	0.000000	4	0.002151	0	0.000000	0	0.000000	90	0.029378	0	0.000000	0	0.000000
5004	16.2	0	0.000000	3	0.001267	1	0.000249	0	0.000000	16	0.004247	0	0.000000	0	0.000000
5005	15.1	1	0.000198	1	0.002180	0	0.000000	0	0.000000	12	0.002245	0	0.000000	0	0.000000
5006	13.9	0	0.000000	1	0.000089	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5007	12.6	74	0.055148	10	0.007225	0	0.000000	0	0.000000	2	0.000319	0	0.000000	0	0.000000
5008	11.4	3	0.000632	3	0.001256	0	0.000000	0	0.000-00	6	0.001675	0	0.000000	0	0.000000
5009	12.0	4	0.002107	6	0.005148	0	0.000000	0	0.000000	3	0.000418	0	0.000000	0	0.000000
5010	12.8	1	0.010180	5	0.002651	1	0.000932	0	0.000000	6	0.000927	0	0.000000	0	0.000000
5011	11.0	3	0.001317	3	0.000768	0	0.000000	0	0.000000	4	0.000900	0	0.000000	0	0.000000
5012	9.8	3	0.003327	2	0.001666	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5013	9.2	8	0.006156	14	0.004711	0	0.000000	0	0.000000	3	0.000473	0	0.000000	1	0.001240
5014	8.0	0	0.000000	13	0.002222	1	0.000046	0	0.000000	3	0.000424	1	0.000366	10	0.001430
5015	8.3	6	0.002028	9	0.003552	0	0.000000	0	0.000000	6	0.001338	0	0.000000	14	0.002777
5016	6.9	0	0.000000	1	0.000037	1	0.000030	0	0.000000	5	0.000947	0	0.000000	2	0.000399
5017	5.7	0	0.000000	17	0.000786	0	0.000000	0	0.000000	0	0.000000	0	0.000000	2	0.000601
5018	4.6	0	0.000000	38	0.001862	0	0.000000	1	0.000084	0	0.000000	0	0.000000	1	0.000831
5019	4.8	0	0.000000	12	0.000332	0	0.000000	0	0.000000	1	0.000155	0	0.000000	2	0.000743
5020	3.7	0	0.000000	40	0.003022	1	0.000150	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5021	3.0	0	0.000000	41	0.002620	0	0.000000	1	0.000118	0	0.000000	0	0.000000	0	0.000000
5022	2.1	0	0.000000	24	0.001584	0	0.000000	2	0.000090	0	0.000000	0	0.000000	2	0.000524
5023	1.4	0	0.000000	9	0.000151	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5024	0.7	0	0.000000	15	0.010543	1	0.000010	0	0.000000	1	0.000307	0	0.000000	0	0.000000
5025	0.3	0	0.000000	63	0.003172	4	0.000179	3	0.000292	0	0.000000	0	0.000000	1	0.000020

Table A-6. Hemlock Lake zoobenthos collected during 1969 and 1970. The less abundant organisms are listed in this table. To obtain a total for a given sample, add the values for each sample (check each organism) to the values for that sample given in Table A-5. Wet weights are shown.

Sample Number	Depth (m)	Date	Number	Weight (gm)
Amphipods				
224	1.37	7-25-69	1	0.000148
325	0.46	8-15-69	1	0.000058
424	0.92	9- 6-69	1	0.000229
1024	0.46	6-12-70	1	0.000012
1025	0.23	6-12-70	1	0.000454
2004	16.02	7- 3-70	1	0.000220
Dragonflies				
22	2.29	6-13-69	1	0.043686
23	1.60	6-13-69	2	0.076687
24	0.92	6-13-69	1	0.008999
124	1.37	7- 4-69	1	0.020766
125	0.69	7- 4-69	1	0.057300
223	1.83	7-25-69	1	0.169671
225	0.69	7-25-69	5	0.055579
321	3.20	8-15-69	1	0.225487
324	0.92	8-15-69	1	0.000118
325	0.46	8-15-69	1	0.152927
424	0.92	9- 6-69	1	0.000233
425	0.46	9- 6-69	1	0.022557
1022	1.83	6-12-70	2	0.151958
2024	0.92	7- 3-70	1	0.081826
2025	0.23	7- 3-70	2	0.005540
3025	0.23	7-24-70	1	0.049046
4022	2.06	8-14-70	2	0.003524
4025	0.23	8-14-70	3	0.079121
5020	3.66	9- 4-70	1	0.202513
5025	0.23	9- 4-70	2	0.400948
Damselflies				
118	5.72	7- 4-69	4	0.004010
424	0.92	9- 6-69	9	0.004751
425	0.46	9- 6-69	2	0.001369
1025	0.23	6-12-70	1	0.003350
4002	17.40	8-14-70	1	0.000409
5025	0.23	9- 4-70	1	0.000038

Table A-6 (Continued)

Sample Number	Depth (m)	Date	Number	Weight (gm)
Trichoptera				
115	7.78	7- 4-69	28	0.016076
5022	2.06	9- 4-70	1	0.000082
Tabanid				
5022	2.06	9- 4-70	1	0.000243
Leeches				
323	1.83	8-15-69	1	0.546294
5017	5.72	9- 4-70	1	0.029607

Table A-7. Section Four Lake zoobenthos collected with an Ekman dredge during 1969 and 1970. Numbers and weights for the seven most abundant taxa are shown in this table for each sample. 125 samples were collected each summer. The less abundant taxa are listed in Table A-8. To verify the total weights for a given sample, consult both tables. Depth is in meters and weight is in grams.

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Amphipoda No.	Amphipoda Wt.	Mayflies No.	Mayflies Wt.	Heleidae No.	Heleidae Wt.	Trichoptera No.	Trichoptera Wt.
6-15-69															
51	18.7	125	0.037484	0	0.000000	0	0.000000	1	0.000248	0	0.000000	0	0.000000	0	0.000000
52	17.8	263	0.129977	2	0.001303	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
53	14.6	216	0.113488	11	0.001340	1	0.000062	2	0.001132	0	0.000000	0	0.000000	0	0.000000
54	16.9	112	0.036[illegible]	10	0.030925	1	0.000286	0	0.000000	0	0.000000	0	0.000000	0	0.000000
55	16.0	20	0.006093	53	0.007247	1	0.000124	0	0.000000	0	0.000000	0	0.000000	0	0.000000
56	13.0	35	0.008992	8	0.007369	1	0.000091	1	0.000[illegible]	0	0.000000	0	0.000000	0	0.000000
57	13.7	29	0.022968	1	0.000192	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
58	12.3	6	0.001411	5	0.001807	1	0.000146	0	0.000000	0	0.000000	1	0.000035	0	0.000000
59	12.[illegible]	34	0.004647	4	0.000405	0	0.000000	0	0.000000	0	0.000000	1	0.000251	0	0.000000
60	11.7	3	0.000785	1	0.000510	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
61	11.7	2	0.000580	8	0.001563	0	0.000[illegible]	0	0.000000	0	0.000000	0	0.000000	1	0.000181
62	8.9	1	0.000207	22	0.002000	1	0.000163	0	0.000000	0	0.000000	0	0.000000	0	0.000000
63	7.8	6	0.001358	51	0.005433	1	0.000009	0	0.000000	1	0.000034	1	0.000336	0	0.000000
64	7.5	16	0.016207	258	0.013302	53	0.006524	0	0.000000	0	0.000000	0	0.000000	0	0.000000
65	9.2	0	0.000000	53	0.006443	1	0.000088	7	0.001474	0	0.000000	2	0.000482	0	0.000000
66	6.4	9	0.001384	84	0.006158	23	0.002117	0	0.000000	0	0.000000	4	0.001198	1	0.000110
67	3.7	4	0.000680	89	0.004919	4	0.000159	20	0.006340	0	0.000000	16	0.002956	0	0.000000
68	4.6	18	0.003336	164	0.008330	7	0.000670	35	0.005132	5	0.000821	17	0.004327	0	0.000000
69	6.2	4	0.000558	72	0.005483	9	0.001051	22	0.004581	2	0.000483	3	0.000782	2	0.000154
70	5.0	10	0.002172	225	0.012618	8	0.000728	9	0.002312	5	0.000972	17	0.004797	0	0.000000
71	3.2	1	0.000541	142	0.000500	3	0.000507	32	0.026150	3	0.001604	12	0.004101	0	0.000000
72	2.5	11	0.001344	112	0.006432	2	0.000214	28	0.005581	4	0.002003	10	0.002080	1	0.000060
73	2.1	0	0.000000	184	0.010559	3	0.003132	37	0.001333	2	0.000421	10	0.001725	0	0.000000
74	0.9	11	0.003425	206	0.012364	11	0.002540	4	0.001286	1	0.000412	7	0.001161	0	0.000000
75	1.4	4	0.001753	200	0.042538	16	0.002381	21	0.019484	1	0.001447	11	0.006448	2	0.002735
7-5-69															
151	19.7	398	0.394441	0	0.000000	0	0.000[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000
15[illegible]	19.2	359	0.469270	0	0.000000	0	0.000[illegible]	0	0.000[illegible]	0	0.000000	0	0.000000	0	0.000000
153	18.3	156	0.055653	51	0.134184	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
154	17.4	12	0.028[illegible]	[illegible]	0.092037	1	0.000[illegible]	[illegible]	0.000[illegible]	0	0.000000	1	0.000903	0	0.000000
155	16.0	45	0.010068	77	0.012093	2	0.000385	0	[illegible]	0	[illegible]	0	0.000[illegible]	0	0.000000
156	14.2	6	[illegible]	17	0.001333	0	[illegible]	0	[illegible]	0	[illegible]	0	0.000000	0	0.000000
157	13.0	70	0.017[illegible]	39	0.014097	0	0.000[illegible]	0	0.000[illegible]	0	0.000000	1	0.000127	0	0.000000
158	12.8	30	0.006[illegible]	[illegible]	0.012[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	1	0.000335	0	0.000000
159	12.3	18	0.001[illegible]	17	0.007423	1	[illegible]	0	[illegible]	0	[illegible]	1	0.000805	0	0.000000
[illegible]	11.2	3	0.0002[illegible]	4	0.003[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	0	0.000000	0	0.000000
161	10.1	0	0.00000[illegible]	[illegible]	0.036[illegible]	4	[illegible]	1	0.001[illegible]	0	[illegible]	0	0.000000	0	0.000000
162	8.3	2	0.000[illegible]	78	0.015103	1	[illegible]	[illegible]	[illegible]	0	0.000000	5	0.001794	0	0.000000
163	8.3	[illegible]	0.005[illegible]	190	0.018[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	3	0.002016	0	0.000000
164	9.2	[illegible]	[illegible]	119	0.007[illegible]	1	0.001[illegible]	4	0.000[illegible]	1	0.000714	2	0.000448	0	0.000[illegible]
165	8.3	20	[illegible]	392	0.027144	3	0.001[illegible]	1	0.001431	1	0.000[illegible]	0	0.000[illegible]	1	0.002571
166	5.7	[illegible]	[illegible]	132	0.017[illegible]	3	0.000[illegible]	6	0.004[illegible]	2	[illegible]	2	0.000719	0	0.000000
167	5.0	[illegible]	0.002[illegible]	57	0.012[illegible]	9	0.000[illegible]	31	0.048[illegible]	0	[illegible]	3	0.001415	4	0.003343
168	1.8	1	0.001[illegible]	13[illegible]	0.012[illegible]	7	0.001[illegible]	0	0.000[illegible]	2	[illegible]	1	0.000725	1	0.000[illegible]

Table A-7 (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Amphipoda No.	Amphipoda Wt.	Mayflies No.	Mayflies Wt.	Heleidae No.	Heleidae Wt.	Trichoptera No.	Trichoptera Wt.
169	4.1	1	0.000604	153	0.018628	12	0.002326	0	0.000000	1	0.000204	7	0.002687	1	0.000446
170	3.7	13	0.005265	109	0.025384	14	0.002677	11	0.007166	2	0.003410	1	0.000476	0	0.000000
171	2.7	3	0.001496	43	0.003544	4	0.000595	1	0.001035	2	0.004788	1	0.000602	0	0.000000
172	2.3	3	0.002026	58	0.010751	4	0.000586	1	0.001208	0	0.000000	0	0.000000	0	0.000000
173	3.0	3	0.001165	81	0.007529	4	0.000620	0	0.000000	1	0.000340	0	0.000000	0	0.000000
174	1.2	22	0.008603	228	0.019800	13	0.001913	11	0.009274	1	0.000655	0	0.000000	0	0.000000
[illegible]	[illegible]	[illegible]	0.000874	93	0.006263	4	[illegible]	7	0.002185	1	0.000803	7	0.001106	0	0.000000
7-25-69															
251	19.7	1123	0.947312	3	0.003898	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
252	18.7	480	0.259524	2	0.002852	1	0.000215	0	0.000000	0	0.000000	0	0.000000	0	0.000000
253	19.4	438	0.587135	14	0.067439	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
254	18.5	286	0.154376	375	0.049310	1	0.000481	0	0.000000	0	0.000000	0	0.000000	0	0.000000
255	17.4	16	0.002096	109	0.011697	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
256	13.2	46	0.005866	30	0.001467	1	0.000322	0	0.000000	1	0.000159	1	0.000010	0	0.000000
257	13.7	33	0.020125	381	0.051125	0	0.000000	2	0.002589	0	0.000000	0	0.000000	0	0.000000
258	12.0	17	0.009033	185	0.040806	0	0.000000	0	0.000000	0	0.000000	4	0.001830	0	0.000000
259	11.0	1	0.000531	150	0.028433	0	0.000000	0	0.000000	0	0.000000	1	0.000214	0	0.000000
260	11.4	1	0.000570	324	0.026003	1	0.000120	0	0.000000	0	0.000000	2	0.000149	0	0.000000
261	10.3	0	0.000000	52	0.007057	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
262	9.2	3	0.002475	150	0.026280	0	0.000000	0	0.000000	1	0.000252	1	0.000077	1	0.004088
263	8.3	17	0.006339	33	0.008026	1	0.000160	1	0.000836	0	0.000000	0	0.000000	1	0.005864
264	9.2	0	0.000000	28	0.006246	0	0.000000	1	0.000291	0	0.000000	0	0.000000	0	0.000000
265	8.3	1	0.000080	46	0.009995	0	0.000000	0	0.000000	0	0.000000	3	0.001206	0	0.000000
266	7.3	0	0.000000	43	0.006635	5	0.000868	5	0.004608	0	0.000000	0	0.000000	0	0.000000
267	5.5	0	0.000000	13	0.003826	3	0.000441	1	0.016308	2	0.000709	0	0.000000	0	0.000000
268	4.8	0	0.000000	13	0.001632	5	0.000431	1	0.000672	3	0.002148	0	0.000000	0	0.000000
269	5.0	0	0.000000	4	0.000853	1	0.000091	3	0.001130	1	0.000173	0	0.000000	0	0.000000
270	4.3	0	0.000000	8	0.003904	1	0.000591	0	0.000000	0	0.000000	0	0.000000	0	0.000000
271	3.2	0	0.000000	110	0.012074	2	0.000471	8	0.001677	1	0.001265	0	0.000000	0	0.000000
272	3.7	0	0.000000	26	0.006374	1	0.000114	5	0.002387	2	0.001160	2	0.000447	0	0.000000
273	2.3	1	0.000415	[illegible]	0.001342	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
274	1.2	0	0.000000	21	0.003564	1	[illegible]	0	0.000000	1	0.000921	1	0.000165	0	0.000000
275	0.5	0	0.000000	19	0.002602	0	0.000000	9	0.001688	0	0.000000	0	0.000000	0	0.000000
8-15-69															
351	19.7	360	0.316086	1	0.001577	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
352	19.7	280	0.341950	20	0.007445	0	0.000000	1	0.000407	0	0.000000	0	0.000000	0	0.000000
353	19.4	146	0.078877	62	0.148463	0	0.000000	0	0.000000	0	0.000000	1	0.000424	0	0.000000
354	18.5	112	0.085041	[illegible]	0.160487	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
355	16.5	493	0.435488	147	0.087398	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
356	14.2	74	0.013131	349	0.087061	1	0.001045	15	0.019278	0	0.000000	0	0.000000	0	0.000000
357	11.0	0	0.000000	185	0.050300	4	0.000941	1	0.000520	0	0.000000	0	0.000000	1	0.001711
358	11.0	0	0.000000	52	0.015136	1	[illegible]	0	0.000000	0	0.000000	0	0.000000	1	0.000637
359	11.2	0	0.000000	25	0.005971	0	[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000
360	11.0	0	0.000000	15	0.003621	0	0.000000	0	0.000000	[illegible]	0.000000	0	0.000000	0	0.000000
361	9.7	5	0.003145	30	0.009534	0	0.000000	0	0.000000	0	0.000000	1	0.000114	0	0.000000
362	9.2	0	0.000000	72	0.008541	3	0.000417	0	0.000000	0	0.000000	0	0.000000	0	0.000000

Table [illegible] (Continued)

Sample Number	Depth	Olignchaeta No.	Olignchaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Amphipoda No.	Amphipoda Wt.	Mayflies No.	Mayflies Wt.	Heleidae No.	Heleidae Wt.	Trichontera No.	Trichontera Wt.
363	8.3	15	0.007483	76	0.014883	6	0.000394	1	0.000577	1	0.001607	0	0.000000	0	0.000000
364	7.5	2	0.000960	30	0.007216	3	0.000390	2	0.001673	0	0.000000	0	.000000	0	0.000000
365	9.2	4	0.002165	153	0.017192	1	0.000043	11	0.016288	0	0.000000	0	0.000000	1	0.000037
366	6.9	3	0.000369	35	0.005275	3	0.000456	1	0.000245	2	0.008254	0	0.000000	0	0.000000
367	6.0	0	0.000000	13	0.005913	0	0.000000	4	0.001816	0	0.000000	1	0.000388	0	0.000000
368	5.3	0	0.000000	5	0.000202	1	0.000138	2	0.000952	0	0.000000	0	0.000000	1	0.000289
369	4.6	1	0.000134	46	0.003389	2	0.000279	1	0.000279	0	0.000000	6	0.000649	2	0.000289
370	3.9	1	0.000013	77	0.005515	7	0.000335	5	0.000396	0	0.000000	1	0.000134	1	0.000708
371	3.2	0	0.000000	23	0.001465	1	0.000064	1	0.000093	0	0.000000	1	0.000091	0	0.000000
372	2.5	0	0.000000	12	0.000751	2	0.000086	1	0.000096	0	0.000000	0	0.000000	0	0.000000
373	1.2	0	0.000000	58	0.003347	4	0.000100	0	0.000000	0	0.000000	8	0.000994	0	0.000000
374	1.6	0	0.000000	51	0.002407	6	0.000222	2	0.000241	0	0.000000	4	0.000126	0	0.000000
375	0.5	0	0.000000	35	0.001618	5	0.000526	37	0.003858	0	0.000000	1	0.000076	0	0.000000
9-6-69															
475	20.1	512	0.411180	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
474	19.9	342	0.775109	2	0.003283	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
473	18.1	88	0.025160	71	0.073864	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
472	19.7	219	0.632133	57	0.019344	0	0.000000	0	0.000000	0	0.000000	1	0.000353	0	0.000000
471	18.3	137	0.070083	44	0.053595	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
470	11.4	0	0.000000	57	0.017942	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
469	11.4	4	0.002229	16	0.010740	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
468	12.2	32	0.004395	68	0.021900	2	0.000376	0	0.000000	0	0.000000	0	0.000000	0	0.000000
467	12.2	28	0.014416	218	0.064953	8	0.001723	0	0.000000	0	0.000000	1	0.000470	0	0.000000
466	12.2	34	0.005916	29	0.014170	0	0.000000	0	0.000000	0	0.000000	1	0.000316	0	0.000000
465	10.5	0	0.000000	75	0.032766	3	0.001103	0	0.000000	0	0.000000	0	0.000000	0	0.000000
464	10.1	0	0.000000	17	0.004612	6	0.001557	1	0.000391	0	0.000000	0	0.000000	0	0.000000
463	9.2	1	0.001245	19	0.007020	2	0.001755	1	0.000173	0	0.000000	0	0.000000	0	0.000000
462	9.6	1	0.000532	17	0.003493	1	0.000276	0	0.000000	0	0.000000	0	0.000000	0	0.000000
461	8.0	0	0.000000	12	0.004235	0	0.000000	3	0.000804	0	0.000000	0	0.000000	0	0.000000
460	6.4	1	0.000406	11	0.002295	0	0.000000	20	0.004973	1	0.000482	0	0.000000	0	0.000000
459	6.0	0	0.000000	3	0.000148	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
458	4.1	0	0.000000	23	0.006938	0	0.000000	8	0.003159	2	0.001926	1	0.000501	0	0.000000
457	6.0	0	0.000000	14	0.002253	0	0.000000	18	0.005197	2	0.000728	0	0.000000	1	0.000200
456	5.3	0	0.000000	6	0.002502	0	0.000000	5	0.001814	0	0.000000	1	0.000145	1	0.000227
455	2.7	1	0.000632	3	0.000446	1	0.000561	1	0.000212	0	0.000000	1	0.000156	0	0.000000
454	1.1	0	0.000000	30	0.005540	1	0.000194	5	0.001433	0	0.000000	2	0.000675	0	0.000000
453	1.4	0	0.000000	6	0.000298	0	0.000000	0	0.000000	0	0.000000	2	0.000376	0	0.000000
452	2.7	0	0.000000	7	0.003346	0	0.000000	3	0.000975	0	0.000000	4	0.000805	0	0.000000
451	0.3	1	0.002240	21	[illegible]	2	0.000283	80	[illegible]	1	0.000106	0	0.000000	0	0.000000
6-12-70															
1051	20.1	433	[illegible]	1	0.000235	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1052	20.1	176	[illegible]	2	0.000270	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1053	19.4	124	[illegible]	11	0.018985	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1054	18.5	125	[illegible]	5	0.000480	1	0.000144	1	0.001444	0	0.000000	0	0.000000	0	0.000000
1055	16.7	109	0.048141	40	0.008187	7	0.002021	0	0.000000	0	0.000000	0	0.000000	0	0.000000

Table A-7 (Continued)

Sample Number	Depth	Oligochaeta		Chironomid L.		Chironomid P.		Amphipoda		Mayflies		Heleidae		Trichoptera	
		No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
1056	12.3	17	0.003504	2	0.000969	7	0.000344	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1057	12.6	17	0.002013	10	0.003160	0	0.000000	1	0.000407	0	0.000000	0	0.000000	0	0.000000
1058	12.0	10	0.003760	5	0.000505	1	0.000145	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1059	11.2	0	0.000000	17	0.002336	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1060	11.0	4	0.000696	57	0.003432	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1061	10.5	0	0.000000	14	0.002332	2	0.000403	0	0.000000	0	0.000000	0	0.000000	1	0.000396
1062	9.8	9	0.001766	11	0.002138	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
1063	8.9	0	0.000000	10	0.002073	3	0.000374	4	0.001480	1	0.000322	0	0.000000	2	0.000210
1064	8.0	5	0.003545	30	0.006840	0	0.000000	0	0.000000	0	0.000000	1	0.000550	2	0.001863
1065	8.0	1	0.001205	48	0.003799	1	0.000254	2	0.000711	1	0.000738	4	0.001591	0	0.000000
1066	6.2	1	0.000895	125	0.007423	6	0.000924	16	0.006418	1	0.000178	3	0.000556	1	0.000132
1067	7.3	0	0.000000	30	0.001600	1	0.000210	5	0.001497	0	0.000000	0	0.000000	2	0.000158
1068	3.7	2	0.000806	27	0.003981	0	0.000000	6	0.002205	1	0.000821	2	0.000574	0	0.000000
1069	4.1	0	0.000000	91	0.006111	1	[illegible]	9	0.003694	1	0.000408	9	0.002798	0	0.000000
1070	4.6	0	0.000000	13	0.001765	0	0.000000	30	0.009409	3	0.002254	6	0.001183	2	0.001456
1071	2.5	0	0.000000	32	0.001492	4	0.000334	4	0.001379	0	0.000000	0	0.000000	1	0.000321
1072	1.8	9	0.003465	188	0.011150	11	0.000767	4	0.001945	0	0.000000	7	0.001382	0	0.000000
1073	2.7	1	0.000938	8	0.000257	2	0.000007	4	0.001667	1	0.000253	1	0.000116	1	0.000025
1074	1.4	4	0.000771	33	0.002726	4	0.000713	3	0.001094	0	0.000000	1	0.000166	0	0.000000
1075	0.7	1	0.000378	79	0.005612	4	0.000171	13	0.006169	0	0.000000	0	0.000000	0	0.000000
7-3-70															
2051	19.7	473	0.249827	26	0.002114	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2052	19.9	476	0.363800	62	0.003808	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2053	19.4	205	0.095493	32	0.005412	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2054	18.5	142	0.029062	58	0.010911	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2055	17.6	40	0.012842	62	0.002948	0	0.000000	0	0.000000	0	0.000000	1	0.000169	0	0.000000
2056	12.0	11	0.000745	7	0.000830	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2057	11.9	4	0.000622	17	0.003580	0	0.000000	1	0.000717	0	0.000000	1	0.000151	0	0.000000
2058	11.9	5	0.000361	21	0.003144	1	0.000110	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2059	11.9	2	0.000164	1	0.000590	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2060	11.7	16	0.002047	3	0.000199	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2061	10.1	20	0.003617	10	0.006423	0	0.000000	2	0.000823	0	0.000000	2	0.000497	0	0.000000
2062	8.7	11	0.006321	[illegible]	0.009408	2	0.000150	2	0.000738	0	0.000000	4	0.001607	1	0.001685
2063	9.6	7	0.002160	14	0.001321	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2064	8.5	21	0.001965	100	0.009743	0	0.000000	2	0.000821	1	0.000068	5	0.001738	1	0.000676
2065	7.3	6	0.002499	39	0.005367	3	0.000570	3	0.001214	0	0.000000	1	0.000328	2	0.000462
2066	5.7	5	0.002030	60	0.001884	[illegible]	0.000199	11	0.005258	3	0.000054	2	0.000630	0	0.000000
2067	6.0	9	0.002124	25	0.007207	1	0.000101	0	[illegible]	0	0.000000	1	0.000139	1	0.000238
2068	4.8	0	0.000000	6	0.000314	0	[illegible]	4	[illegible]	0	0.000000	0	0.000000	1	0.000071
2069	4.1	4	[illegible]	11	0.000363	1	[illegible]	1	[illegible]	0	0.000000	0	0.000000	0	0.000000
2070	4.6	2	0.000270	27	0.002702	0	[illegible]	6	0.002613	0	0.000000	0	0.000000	2	0.002582
2071	3.7	24	[illegible]	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.000000	4	0.001180	0	0.000000
2072	2.7	3	[illegible]	14	0.001804	1	[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000
2073	1.8	3	[illegible]	6	0.000441	0	[illegible]	0	[illegible]	0	0.000000	0	0.000000	0	0.000000
2074	0.9	13	0.013121	40	0.006092	0	0.000000	3	[illegible]	0	0.000000	1	0.000110	0	0.000000
2075	0.3	10	[illegible]	113	0.009120	15	0.000768	23	0.008811	1	[illegible]	1	0.000025	0	0.000000

Table 3-7 (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Amphipoda No.	Amphipoda Wt.	Mayflies No.	Mayflies Wt.	Heleidae No.	Heleidae Wt.	Trichoptera No.	Trichoptera Wt.
7-24-70															
3051	19.9	217	0.146485	76	0.007891	2	0.000358	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3052	19.9	468	0.261606	22	0.001904	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3053	19.7	108	0.033697	86	0.037453	1	0.000130	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3054	18.7	474	0.161224	64	0.015958	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3055	18.3	177	0.059882	40	0.018658	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3056	11.2	10	0.001459	22	0.004791	2	0.000557	0	0.000000	0	0.000000	1	0.000024	0	0.000000
3057	11.2	24	0.003274	29	0.005697	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3058	11.4	12	0.004448	43	0.007236	1	0.000202	1	0.000572	0	0.000000	0	0.000000	0	0.000000
3059	12.0	2	0.000116	1	0.000063	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3060	11.7	14	0.001423	12	0.002619	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3061	9.6	17	0.004405	13	0.001221	0	0.000000	1	0.000374	0	0.000000	2	0.000596	0	0.000000
3062	8.9	12	0.002601	16	0.002630	1	0.000088	0	0.000000	0	0.000000	0	0.000000	0	0.000000
3063	8.7	12	0.004418	54	0.007724	2	0.000375	2	0.000194	1	0.000308	1	0.000303	0	0.000000
3064	7.5	8	0.001540	26	0.003210	3	0.000463	4	0.002737	1	0.001406	0	0.000000	0	0.000000
3065	6.4	17	0.008398	44	0.009835	4	0.000635	4	0.001733	0	0.000000	2	0.001099	1	0.001493
3066	[illegible]	[illegible]	[illegible]	17	[illegible]	1	[illegible]	0	0.000000	1	0.000318	3	0.001016	0	0.000000
3067	5.5	6	0.001864	35	0.004836	3	0.000407	3	0.003137	1	0.000131	1	0.000441	0	0.000000
3068	5.0	10	0.003638	32	0.003744	2	0.000244	6	0.003922	0	0.000000	1	0.000008	0	0.000000
3069	5.5	0	0.000000	28	0.003621	4	0.000484	5	0.002208	1	0.000126	0	0.000000	0	0.000000
3070	3.7	2	0.000169	38	0.003373	5	0.000645	11	0.005210	2	0.000548	4	0.000954	0	0.000000
3071	3.2	5	0.001705	8	0.000580	0	0.000000	0	0.000000	0	0.000000	2	0.000232	0	0.000000
3072	2.5	2	0.000160	23	0.002152	2	0.000130	3	0.001774	0	0.000000	4	0.000656	0	0.000000
3073	2.5	1	0.000481	40	0.003466	2	0.000141	1	0.000857	0	0.000000	5	0.000444	0	0.000000
3074	0.7	4	[illegible]	30	0.003721	1	0.000088	1	0.000620	0	0.000000	2	0.000179	0	0.000000
3075	0.3	2	0.000587	152	[illegible]	6	0.000247	34	0.007336	0	0.000000	1	0.000263	0	0.000000
8-14-70															
4051	20.1	178	0.181878	36	0.015199	1	0.000204	0	0.000000	0	0.000000	0	0.000000	0	0.000000
4052	19.7	68	0.019280	17	0.004678	2	0.000723	1	0.000263	0	0.000000	0	0.000000	0	0.000000
4053	19.7	140	0.033098	82	0.026325	1	0.002347	0	0.000000	0	0.000000	1	0.000083	0	0.000000
4054	19.7	537	0.187840	52	0.014616	1	0.000175	0	0.000000	0	0.000000	0	0.000000	0	0.000000
4055	18.1	18	0.012623	15	0.007328	1	[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000
4056	11.0	8	0.001106	17	[illegible]	[illegible]	[illegible]	3	0.000347	0	0.000000	0	0.000000	0	0.000000
4057	11.4	32	0.007731	[illegible]	[illegible]	[illegible]	[illegible]	3	0.006471	1	0.000020	1	0.000012	0	0.000000
4058	11.2	22	0.005540	39	[illegible]	1	[illegible]	[illegible]	0.005214	0	0.000000	0	[illegible]	0	0.000000
4059	12.0	1	0.000157	11	[illegible]	[illegible]	0.007378	[illegible]	[illegible]	[illegible]	[illegible]	0	0.000000	0	0.000000
4060	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	0.004471	0	0.000000	0	0.000000	0	0.000000
4061	10.1	1	[illegible]	71	[illegible]	1	[illegible]	3	[illegible]	1	0.000240	0	0.000000	0	0.000000
4062	8.9	19	[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.000000	1	0.000041	0	0.000000
4063	9.6	5	[illegible]	28	[illegible]	0	[illegible]	11	[illegible]	0	[illegible]	0	0.000000	0	0.000000
4064	7.8	2	[illegible]	18	[illegible]	1	[illegible]	12	[illegible]	4	0.003132	0	[illegible]	0	0.000000
4065	8.7	2	[illegible]	31	[illegible]	[illegible]	[illegible]	17	0.001151	0	0.000000	0	[illegible]	[illegible]	[illegible]
4066	7.7	1	[illegible]	42	[illegible]	[illegible]	[illegible]	8	[illegible]	1	0.000358	0	0.000000	0	0.000000

Table A-7 (Continued)

Sample Number	Depth	Oligochaeta No.	Oligochaeta Wt.	Chironomid L. No.	Chironomid L. Wt.	Chironomid P. No.	Chironomid P. Wt.	Amphipoda No.	Amphipoda Wt.	Mayflies No.	Mayflies Wt.	Heleidae No.	Heleidae Wt.	Trichoptera No.	Trichoptera Wt.
4067	4.1	3	0.001033	43	0.005801	1	0.00007[illegible]	[illegible]	0.001236	2	0.001773	1	0.0001	0	0.000000
4068	6.[illegible]	20	0.004225	3	0.000701	0	0.000000	1	0.000037	0	0.000000	0	0.000000	0	0.000000
4069	5.0	4	0.000682	35	0.002083	0	0.000000	9	0.000630	0	0.000000	0	0.000000	0	0.000000
4070	4.3	8	0.001202	16	0.000893	0	0.000000	1	0.000754	0	0.000000	0	0.000000	0	0.000000
4071	3.7	2	0.000064	30	0.003245	0	0.000000	19	0.004432	0	0.000000	0	0.000000	0	0.000000
4072	2.5	3	0.000714	18	0.001111	1	0.000013	0	0.000000	0	0.000000	0	0.000000	1	0.000222
4073	2.1	3	0.000726	22	0.002142	1	0.000126	5	0.002548	1	0.000064	0	0.000000	0	0.000000
4074	1.2	7	0.001158	57	0.004818	3	0.000139	40	0.007304	0	0.000000	0	0.000000	0	0.000000
4075	0.3	5	0.000992	31	0.004376	2	0.000128	18	0.002500	1	0.000050	0	0.000000	0	0.000000
9-4-70															
5051	19.9	318	0.318906	36	0.013950	2	0.000600	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5052	20.1	168	0.181866	53	0.005296	1	0.000295	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5053	19.7	186	0.181879	57	0.000000	3	0.009677	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5054	19.0	121	0.163979	43	0.017090	3	0.000600	0	0.000000	0	0.000000	1	0.000878	0	0.000000
5055	18.1	103	0.121870	69	0.008579	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5056	[illegible]	3	0.000588	3	0.0007[illegible]	0	0.000000	0	0.000000	0	0.000000	2	0.000208	0	0.000000
5057	12.0	6	0.001020	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5058	11.0	1	0.000018	14	0.000707	2	0.000117	10	0.004700	1	0.000082	0	0.000000	1	0.000153
5059	12.3	5	0.000627	18	0.000630	1	0.000121	0	0.000000	0	0.000000	3	0.000026	0	0.000000
5060	11.4	18	0.001878	9	0.000618	3	0.000178	27	0.025896	4	0.000179	1	0.000038	2	0.00181[illegible]
5061	10.1	0	0.000000	10	0.00[illegible]	[illegible]	[illegible].000000	1	0.002827	2	0.000058	0	0.000000	1	0.[illegible]035
5062	8.5	10	0.00554[illegible]	[illegible]	0.003818	1	0.000212	18	0.002550	4	0.000145	0	0.000000	1	0.000259
5063	8.9	12	0.002072	10	0.002122	1	0.000089	15	0.025109	2	0.000076	0	0.000000	0	0.000000
5064	7.5	0	0.000000	16	0.00111[illegible]	0	0.000000	91	0.005985	4	0.000491	0	0.000000	2	0.000410
5065	8.7	6	0.001848	6	0.0006[illegible]	1	0.000115	11	0.003880	1	0.000013	0	0.000000	3	0.006150
5066	8.0	8	0.001[illegible]72	13	0.0017[illegible]	0	0.000000	32	0.006377	0	0.000000	0	0.000000	2	0.001937
5067	6.0	12	0.003628	1	0.000072	0	0.000000	0	0.003883	0	0.000000	1	0.000073	0	0.000000
5068	6.9	5	0.001647	9	0.000520	0	0.000000	10	0.002522	2	0.000450	0	0.000000	0	0.000000
5069	4.6	4	0.002513	16	0.00007[illegible]	0	0.000000	5	0.002007	1	0.000091	2	0.000202	1	0.000739
5070	4.3	0	0.000000	17	0.0018[illegible]	1	0.000171	10	0.002782	1	0.000059	1	0.003446	1	0.002432
5071	3.2	0	0.000000	21	0.00194[illegible]	1	0.000315	14	0.004981	4	0.000135	0	0.000000	1	0.000595
5072	0.5	0	0.000000	17	0.0015[illegible]	0	0.000000	[illegible]	0.008030	0	0.000000	1	0.000085	0	0.000000
5073	2.1	0	0.000000	0	0.000[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000	0	0.000000
5074	1.4	1	0.001053	21	0.0013[illegible]	2	0.000092	14	0.003673	0	0.000000	0	0.000000	1	0.001209
5075	0.9	21	0.005237	42	0.001363	2	0.00006[illegible]	0	0.000000	0	0.000000	0	0.000000	0	0.000000

Table A-8. Section Four Lake zoobenthos collected during 1969 and 1970. The less abundant organisms are listed in this table. To obtain a total for a given sample, add the values for each sample (check each organism) to the values for that sample given in Table A-7. Wet weights are shown.

Sample Number	Depth (m)	Date	Number	Weight (gm)
Oligochaetes (Megadriles)				
55	16.02	6-15-69	1	0.004690
57	13.73	6-15-69	11	0.229702
58	12.36	6-15-69	2	0.020609
59	12.82	6-15-69	2	0.029082
60	11.67	6-15-69	4	0.821241
158	12.82	7- 5-69	1	0.053231
161	10.07	7- 5-69	1	0.314032
252	18.77	7-25-69	1	0.037648
256	13.28	7-25-69	1	0.018359
466	12.13	9- 6-69	3	0.013296
1056	12.36	6-12-70	2	0.070588
1057	12.59	6-12-70	5	0.091363
3061	9.61	7-24-70	1	0.346751
3067	5.49	7-24-70	1	0.533722
4071	3.66	8-14-70	1	0.209138
5057	11.90	9- 4-70	2	0.942075
Dragonflies				
71	3.20	6-15-69	2	0.045291
73	2.06	6-15-69	4	0.002955
170	3.66	7- 5-69	1	0.001424
173	2.98	7- 5-69	1	0.011425
174	1.14	7- 5-69	1	0.023480
369	4.58	8-15-69	1	0.006573
374	1.60	8-15-69	1	0.004726
1068	3.66	6-12-70	2	0.018994
2075	0.23	7- 3-70	1	0.028874
4060	10.99	8-14-70	1	0.000113
4067	4.12	8-14-70	1	0.000409
4069	5.04	8-14-70	1	0.000445
4070	4.35	8-14-70	1	0.000168
4074	1.14	8-14-70	2	0.097749
4075	0.23	8-14-70	2	0.015670
5066	8.01	9- 4-70	1	0.001060
5074	1.37	9- 4-70	1	0.001092

Table A-8 (Continued)

Sample Number	Depth (m)	Date	Number	Weight (gm)
Damselflies				
58	12.36	6-15-69	1	0.001010
63	7.78	6-15-69	1	0.001154
65	9.16	6-15-69	1	0.000705
161	10.07	7- 5-69	2	0.005000
163	8.24	7- 5-69	2	0.003253
266	7.33	7-25-69	1	0.002526
268	4.81	7-25-69	1	0.001913
363	8.24	8-15-69	1	0.000041
364	7.55	8-15-69	2	0.001018
365	9.16	8-15-69	2	0.001315
368	5.27	8-15-69	1	0.000148
369	4.58	8-15-69	1	0.000684
461	8.01	9- 6-69	1	0.000173
457	5.95	9- 6-69	2	0.000908
456	5.27	9- 6-69	9	0.008156
453	1.37	9- 6-69	1	0.003337
1065	8.01	6-12-70	2	0.004232
1067	7.33	6-12-70	1	0.002547
1070	4.58	6-12-70	1	0.002735
2066	5.72	7- 3-70	1	0.002653
2070	4.58	7- 3-70	1	0.000677
3070	3.66	7-24-70	2	0.010770
3072	2.52	7-24-70	1	0.000063
4063	9.61	8-14-70	2	0.000390
4064	7.78	8-14-70	1	0.000444
4066	7.33	8-14-70	1	0.000885
4067	4.12	8-14-70	2	0.001389
4070	4.35	8-14-70	1	0.003097
4071	3.66	8-14-70	3	0.002754
5058	10.99	9- 4-70	1	0.000003
5060	11.45	9- 4-70	1	0.000004
5062	8.47	9- 4-70	3	0.005000
5064	7.55	9- 4-70	2	0.001896
5066	8.01	9- 4-70	1	0.006620
5068	6.87	9- 4-70	1	0.002077
165	8.47	7- 5-69	2	0.000771
5069	4.58	9- 4-70	1	0.000695
5070	4.35	9- 4-70	1	0.000290
5072	0.46	9- 4-70	1	0.000046
5074	1.37	9- 4-70	1	0.000973

Table A-8 (Continued)

Sample Number	Depth (m)	Date	Number	Weight (gm)
Chaoborus Pupae				
1067	7.33	6-12-70	1	0.000749
Clams				
161	10.07	7- 5-69	1	0.033548
1060	10.99	6-12-70	1	0.004714
2057	10.99	7- 3-70	1	0.004614
2062	8.70	7- 3-70	2	0.007890
4058	11.22	8-14-70	1	0.001932
4060	10.99	8-14-70	1	0.003084
4065	8.70	8-14-70	1	0.022210
4071	3.66	8-14-70	1	0.007647
Tabanids				
371	3.20	8-15-69	1	0.000580
373	1.14	8-15-69	1	0.002152
374	1.60	8-15-69	2	0.001375
375	0.46	8-15-69	1	0.006476
451	0.23	9- 6-69	2	0.013576
1065	8.01	6-12-70	1	0.001660
2074	0.92	7- 3-70	4	0.000255
3067	5.49	7-24-70	1	0.000652
3068	5.04	7-24-70	1	0.008910
3070	3.66	7-24-70	1	0.000661
3072	2.52	7-24-70	8	0.000643
3073	2.52	7-24-70	5	0.001622
3074	0.69	7-24-70	3	0.001811
4067	4.12	8-14-70	1	0.001217
4072	2.52	8-14-70	1	0.000527
4073	2.06	8-14-70	2	0.001474
4074	1.14	8-14-70	1	0.001771
5066	8.01	9- 4-70	1	0.004368
5068	6.87	9- 4-70	1	0.003284
5070	4.35	9- 4-70	4	0.011280
5072	0.46	9- 4-70	2	0.004249
5074	1.37	9- 4-70	5	0.011580
5075	0.92	9- 4-70	3	0.008520

Table A-8 (Continued)

Sample Number	Depth (m)	Date	Number	Weight (gm)
Megaloptera				
452	2.75	9- 6-69	1	0.002803
3060	11.67	7-24-70	1	0.000092
3063	8.70	7-24-70	1	0.000083
3075	0.23	7-24-70	1	0.000070
4056	10.99	8-14-70	1	0.000411
4067	4.12	8-14-70	1	0.000526

Table A-9. Area-capacity table for Hemlock Lake based on January 1957 survey of the lake.

Max. Depth (m)	Area (m^2)	Volume (m^3)
0.0	0	0
0.5	555	0510
1.0	1110	1010
1.5	1665	1520
2.0	2220	2030
2.5	2775	2540
3.0	3246	3860
3.5	3638	5950
4.0	4030	8040
4.5	4422	10130
5.0	4813	12220
5.5	5205	14320
6.0	5469	16720
6.5	5556	19570
7.0	5642	22420
7.5	5729	25260
8.0	5816	28110
8.5	5902	30960
9.0	6161	34140
9.5	6782	38030
10.0	7403	41920
10.5	8025	45810
11.0	8646	49690
11.5	9267	53580
12.0	9851	57760
12.5	10304	62920
13.0	10758	68090
13.5	11220	73390
14.0	11723	79260
14.5	12225	85150
15.0	12733	91140
15.5	13280	97810
16.0	13826	104490
16.5	14390	111260
17.0	15146	119020
17.5	15903	126780
18.0	16659	134540
18.5	17416	142300
19.0	18172	150060
19.5	18928	157830
20.0	19685	165590
20.5	20441	173350
21.0	21198	181110
21.5	21954	188870
22.0	22711	196630
22.5	23467	204400

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Table A-10 . Area-capacity table for Section Four Lake based on January 1957 survey of the lake.

Max. Depth (m)	Area (m^2)	Volume (m^3)	Max. Depth (m)	Area (m^2)	Volume (m^3)
0.0	0	0	20.5	12244	126240
0.5	441	0400	21.0	12566	131300
1.0	882	0810	21.5	12888	136370
1.5	1323	1210	22.0	13210	141440
2.0	1764	1610	22.5	13532	146500
2.5	2206	2020			
3.0	2610	3110			
3.5	2979	4860			
4.0	3348	6600			
4.5	3717	8350			
5.0	4086	10090			
5.5	4455	11840			
6.0	4712	13890			
6.5	4812	16370			
7.0	4912	18860			
7.5	5012	21340			
8.0	5112	23830			
8.5	5212	26320			
9.0	5371	28990			
9.5	5653	32050			
10.0	5935	35110			
10.5	6217	38170			
11.0	6499	41230			
11.5	6782	44290			
12.0	7082	47510			
12.5	7442	51290			
13.0	7803	55070			
13.5	8147	58930			
14.0	8409	63190			
14.5	8672	67440			
15.0	8932	71750			
15.5	9174	76390			
16.0	9417	81040			
16.5	9666	85710			
17.0	9989	90780			
17.5	10311	95840			
18.0	10633	100910			
18.5	10955	105980			
19.0	11277	111040			
19.5	11599	116110			
20.0	11922	121170			

Table A-11. Hemlock Lake calcium, sodium, potassium, magnesium, dissolved organic matter (D.O.M.) and particulate organic matter (P.O.M.) collected during 1970. Samples were collected from six depths seven times during the summer. The mean concentration for the entire lake is shown. These analyses were made by R.G. Wetzel.

	Depth (m)							
	0.0	2.8	6.5	10.1	12.8	14.6	15.6	Mean
Calcium								
VI-7-70	38.4	43.2	46.8	46.7	57.9	102.5	--	--
VI-13-70	38.7	39.2	47.2	45.8	47.1	--	111.0	47.7
VI-18-70	36.8	38.3	44.0	55.2	55.5	--	57.0	44.9
VI-27-70	33.3	34.5	46.3	49.0	49.1	--	48.9	41.8
VII-17-70	33.8	37.2	44.0	45.0	44.9	--	44.9	40.8
VIII-15-70	55.3	57.8	59.3	52.0	50.4	--	50.9	55.4
IX-5-70	49.5	50.3	50.3	50.9	50.3	--	50.9	50.3
Sodium								
VI-7-70	1.75	1.45	2.12	2.08	2.22	2.57	--	--
VI-13-70	1.55	1.50	2.05	2.14	2.14	--	3.00	1.90
VI-18-70	1.50	1.65	2.00	2.14	2.15	--	2.22	1.87
VI-27-70	1.70	1.72	2.08	2.05	2.11	--	2.12	1.92
VII-17-70	1.90	1.98	2.09	2.14	2.15	--	2.11	2.04
VIII-15-70	2.07	2.08	2.05	2.07	2.05	--	2.11	2.07
IX-5-70	2.07	2.05	2.07	2.05	2.14	--	2.11	2.07

Table Λ-11 (Continued)

	Depth (m)							
	0.0	2.8	6.5	10.1	12.8	14.6	15.6	Mean
Potassium								
VI-7-70	0.60	0.63	0.78	0.80	1.05	1.78	--	--
VI-13-70	0.58	0.55	0.68	0.75	0.75	--	2.62	0.78
VI-18-70	0.52	0.52	0.85	1.18	1.19	--	1.23	0.81
VI-27-70	0.60	0.70	0.95	1.00	1.02	--	0.97	0.84
VII-17-70	0.85	0.90	1.02	1.02	1.03	--	1.01	0.96
VIII-15-70	1.00	1.00	1.07	1.03	1.05	--	1.05	1.03
IX-5-70	0.96	0.96	0.96	0.99	1.05	--	1.00	0.98
Magnesium								
VI-7-70	8.0	8.8	10.5	11.3	12.3	14.5	--	--
VI-13-70	9.1	9.2	11.3	11.7	11.9	--	15.9	10.8
VI-18-70	9.3	9.8	11.7	13.5	13.2	--	12.6	11.3
VI-27-70	8.4	8.7	11.4	11.1	11.6	--	10.6	10.1
VII-17-70	9.7	9.8	9.8	10.3	10.6	--	10.3	10.0
VIII-15-70	10.5	10.7	10.7	10.2	11.0	--	10.9	10.6
IX-5-70	10.3	10.3	10.0	10.0	10.2	--	10.6	10.2
D.O.M.								
VI-7-70	7.12	7.33	6.99	7.63	7.99	8.39	--	--
VI-13-70	7.04	6.56	7.24	6.93	6.73	--	9.14	7.04
VI-18-70	6.17	6.54	6.36	5.99	6.26	--	6.53	6.33
VII-17-70	8.84	8.51	7.91	9.28	8.72	--	9.24	8.60
VIII-15-70	6.82	6.74	6.48	6.67	6.21	--	4.68	6.49
IX-5-70	10.32	11.02	10.29	10.21	9.42	--	10.89	10.46

Table A-11 (Continued)

	Depth (m)							
P.O.M.	0.0	2.8	6.5	10.1	12.8	14.6	15.6	Mean
VI-7-70	287.6	756.2	981.6	916.3	1345.3	2627.4	--	--
VI-13-70	857.0	893.3	759.9	1580.1	1408.6	--	3661.1	1195.7
VI-18-70	642.5	1287.0	641.3	1100.9	1026.8	--	1161.4	972.9
VI-27-70	1619.1	1915.6	1963.1	1635.9	1774.3	--	1774.3	1818.3
VII-17-70	693.2	993.4	819.2	566.4	554.5	--	643.5	776.7
VIII-15-70	148.3	156.2	207.6	128.5	164.1	--	243.2	170.0
IX-5-70	591.1	444.8	765.1	377.6	319.7	--	306.4	513.2

Table A-12. Section Four Lake calcium, sodium, potassium, magnesium, dissolved organic matter (D.O.M.) and particulate organic matter (P.O.M.) collected during 1970. Samples were collected from six depths seven times during the summer. The mean concentration for the entire lake is shown. These analyses were made by R.G. Wetzel.

	Depth (m)							
	0.0	3.7	7.4	11.0	14.6	17.4	18.2	Mean
Calcium								
VI-7-70	51.5	55.0	58.4	57.5	57.5	57.5	--	--
VI-13-70	53.0	56.5	58.0	56.5	58.0	--	58.2	56.0
VI-18-70	55.0	55.6	55.6	55.7	58.8	--	58.5	56.0
VI-27-70	55.7	56.0	56.0	57.0	56.9	--	56.2	56.2
VII-17-70	55.0	53.4	54.5	54.8	55.0	--	55.0	54.4
VIII-15-70	52.8	52.6	53.2	49.8	52.8	--	52.8	52.3
IX-5-70	52.8	52.6	52.8	51.6	52.8	--	53.2	52.6
Sodium								
VI-7-70	2.88	3.25	3.28	3.20	3.08	3.20	--	--
VI-13-70	2.95	3.05	3.22	3.08	3.16	--	3.18	3.09
VI-18-70	3.04	3.00	3.06	3.13	3.22	--	3.13	3.07
VI-27-70	3.15	3.15	3.13	3.15	3.17	--	3.13	3.15
VII-17-70	2.81	3.20	3.20	3.09	3.23	--	3.21	3.12
VIII-15-70	3.17	3.10	3.11	3.17	3.08	--	3.12	3.12
IX-5-70	3.16	3.15	3.17	3.21	3.17	--	3.13	3.17

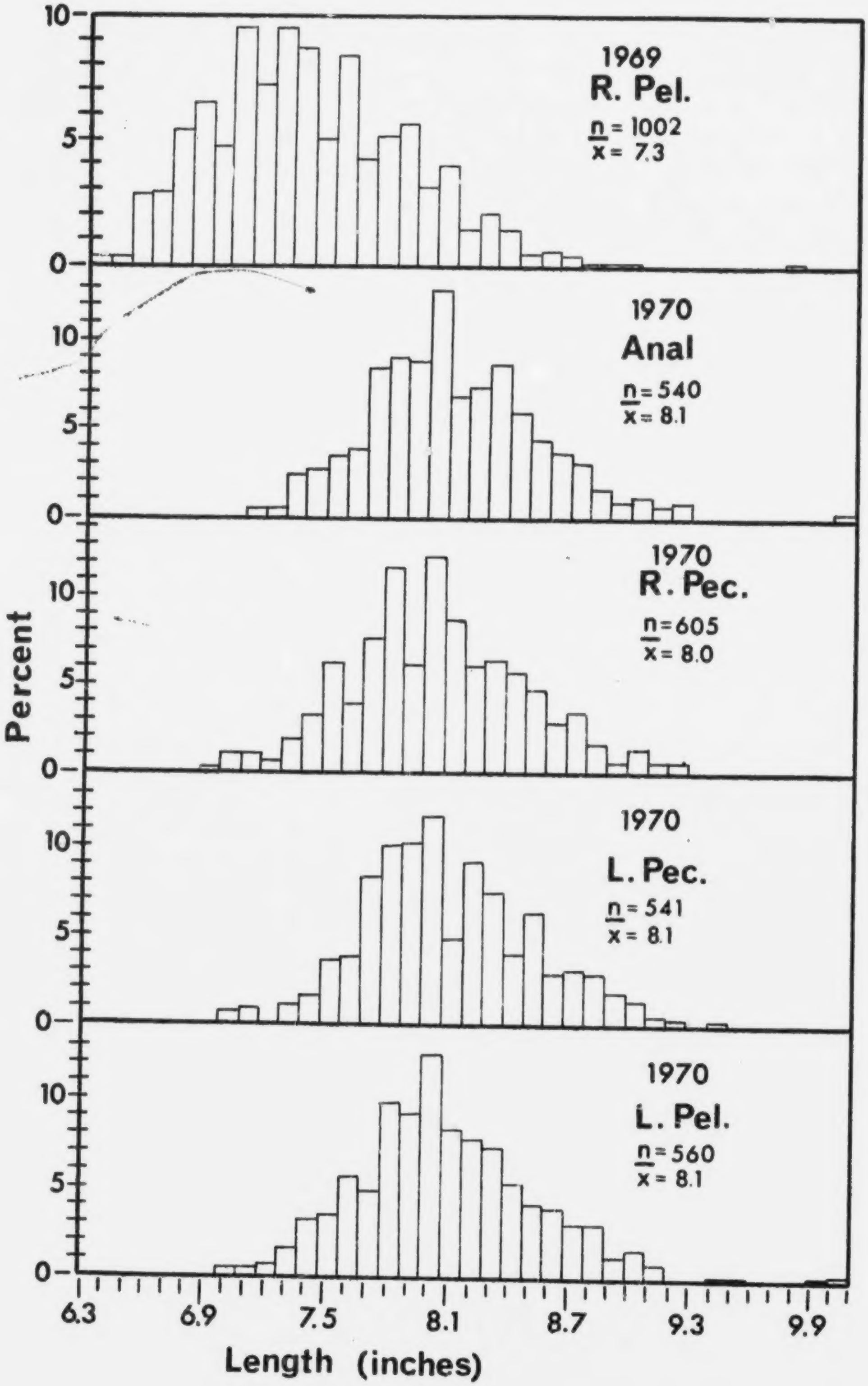
Table A-12 (Continued)

	Depth (m) 0.0	3.7	7.4	11.0	14.6	17.4	18.2	Mean
Potassium								
VI-7-70	0.58	0.69	0.64	0.65	0.65	0.65	--	--
VI-13-70	0.63	0.63	0.64	0.64	0.65	--	0.64	0.64
VI-18-70	0.67	0.63	0.63	0.64	0.69	--	0.64	0.65
VI-27-70	0.59	0.60	0.57	0.57	0.59	--	0.58	0.58
VII-17-70	0.57	0.58	0.57	0.57	0.64	--	0.55	0.58
VIII-15-70	0.60	0.60	0.60	0.58	0.57	--	0.59	0.59
IX-5-70	0.60	0.62	0.60	0.60	0.61	--	0.59	0.61
Magnesium								
VI-7-70	15.2	16.4	18.7	17.2	18.7	16.8	--	--
VI-13-70	15.1	15.7	17.0	16.4	16.0	--	15.9	16.0
VI-18-70	16.0	16.5	14.9	14.6	15.1	--	14.1	15.5
VI-27-70	13.9	12.9	11.9	11.3	11.1	--	10.4	12.3
VII-17-70	10.3	10.1	10.3	9.9	8.9	--	9.2	10.0
VIII-15-70	10.3	10.3	9.2	9.2	9.3	--	10.3	9.8
IX-5-70	10.4	10.2	9.9	10.3	10.6	--	10.4	10.2
D.O.M.								
VI-7-70	6.63	2.57	2.42	2.43	2.20	2.57	--	--
VI-13-70	3.45	2.77	2.48	2.79	2.68	--	2.23	2.79
VI-18-70	3.09	2.80	2.67	2.80	2.56	--	2.42	2.78
VII-17-70	3.49	3.78	3.34	3.49	3.54	--	3.66	3.55
VIII-15-70	3.15	2.53	3.09	2.47	2.32	--	2.90	2.74
IX-5-70	6.75	5.81	6.93	4.76	6.90	--	6.26	6.18

Table A-12 (Continued)

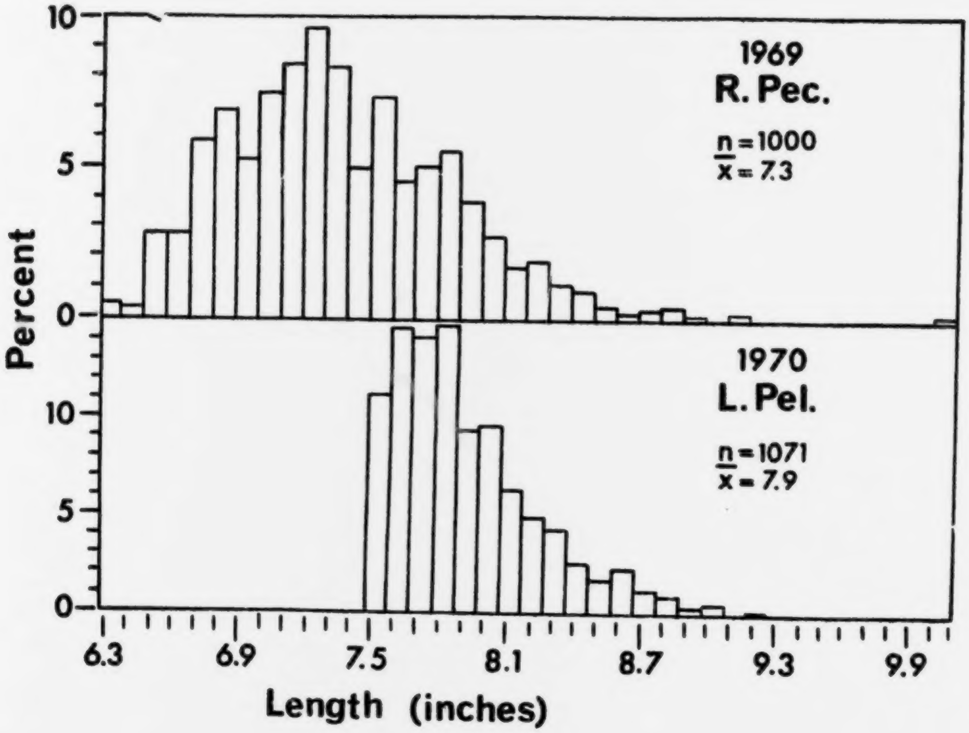
P.O.M.	Depth (m) 0.0	3.7	7.4	11.0	14.6	17.4	18.2	Mean
VI-7-70	140.4	168.0	156.2	247.1	227.4	345.0	--	--
VI-13-70	140.4	136.4	172.0	215.5	144.3	--	191.8	161.4
VI-18-70	310.4	381.6	405.3	385.5	425.0	--	322.2	378.0
VI-27-70	417.1	405.3	440.9	452.7	480.4	--	531.8	436.2
VII-17-70	128.5	81.0	132.4	140.4	124.6	--	132.4	117.1
VIII-15-70	259.0	176.0	235.3	187.8	203.6	--	160.1	207.4
IX-5-70	148.3	199.7	211.5	259.0	148.3	--	191.8	198.0

Figure A-1. Length histograms of hatchery reared rainbow trout at time of stocking in Hemlock Lake during June 6, 1969 and June 25, 1970. Only one lot of fish were stocked during 1969, whereas four lots were stocked during 1970. Each lot received a separate fin clip. Total numbers (n), average fish lengths ($\bar{x}$) and fin clips for each lot are shown.


1969
R. Pel.
n = 1002
x = 7.3
1970
Anal
n = 540
x = 8.1
1970
R. Pec.
n = 605
x = 8.0
1970
L. Pec.
n = 541
x = 8.1
1970
L. Pel.
n = 560
x = 8.1
Percent
0
5
10
6.3
6.9
7.5
8.1
8.7
9.3
9.9
Length (inches)

466

Figure A-2. Length histograms of hatchery reared rainbow trout at time of stocking in Section Four Lake during June 6, 1969 and May 23, 1970. One lot was stocked each year. Total numbers (n), average fish-lengths ($\overline{x}$) and fin clips for each lot are shown.


10
5
0
Percent
10
5
0
1969
R. Pec.
n = 1000
x̄ = 7.3
1970
L. Pel.
n = 1071
x̄ = 7.9
6.3
6.9
7.5
8.1
8.7
9.3
9.9
Length (inches)

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